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# AIRCRAFT REMOTE SENSING
# OF SOIL MOISTURE
# AND HYDROLOGIC PARAMETERS
## Chickasha, Okla., and Riesel, Tex.,
## 1978 Data Report

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# CONTENTS

# AIRCRAFT REMOTE SENSING OF SOIL MOISTURE AND HYDROLOGIC PARAMETERS

## CHICKASHA, OKLA., AND RIESEL, TEX., 1978 DATA REPORT[1]

T.J. Jackson, T.J. Schmugge, G.C. Coleman, C. Richardson,
A. Chang, J. Wang, and E.T. Engman[2]

## ABSTRACT

Experiments were conducted to evaluate aircraft remote sensing techniques for hydrology in a wide range of physiographic and climatic regions using several sensor platforms. The data collected on May 1, 12, and 30, 1978, in two semiarid areas-- Chickasha, Okla., and Riesel, Tex., are reported. Soil moisture observations, climatic data, and the remote sensing data collected using thermal infrared, passive microwave, and active microwave systems are reported.

## INTRODUCTION

Cooperative investigations were conducted during May 1978 by the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) as part of a project to evaluate remote sensing in hydrologic studies with primary emphasis on measurements. Participants in the study were the NASA Goddard Space Flight Center and the USDA-SEA-AR Hydrology Laboratory, Southern Plains Watershed and Water Quality Labortory and the Grassland, Soil, and Water Laboratory.

Experiments were planned to evaluate aircraft remote sensing techniques in a wide range of physiographic and climatic regions using several sensor platforms. This report deals with ground observations and aircraft remote sensing experiments conducted in two semiarid areas-- Chickasha, Okla., and Riesel, Tex.

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[1] Cooperative investigations of the Science and Education Administration, U.S. Department of Agriculture, and the National Aeronautics Space Administration

[2] T.J. Jackson, Hydrologist, and E.T. Engman, Chief, USDA-SEA Hydrology Lab, Beltsville, Md. 20705. G.C. Coleman, Hydraulic Engineer, USDA-SEA, Southern Plains Watershed and Water Quality Lab, Chickasha, Okla. 73018. C. Richardson, Agricultural Engineer, USDA-SEA Grassland, Soil and Water Lab, Temple, Tex. 76501. T.J. Schmugge, Senior Scientist, A. Chang and J. Wang, Scientists, NASA Goddard Space Flight Center, Greenbelt, Md. 20771.

# EXPERIMENTAL DESIGN

## General

Experiments were designed to collect remote sensing data concurrent with ground observations of hydrologically significant parameters and phenomena, primarily soil moisture within several surface layers. An important feature was the observations made on intensively monitored watersheds. In some cases the watershed size was approximetely the same size as the sensor ground resolution element.

In 1978 three successful flights were made on May 1, 12 and 30, over the test sites in Chickasha, Okla., and Riesel, Tex. The following sections describe the ground sampling procedures, general climatological observations and the remote sensing systems that were employed.

## Ground Sampling Procedure

### Chickasha, Okla., test site

The study sites and watersheds in Oklahoma were in the Washita River Experimental Watershed, Chickasha, area which is monitored by the USDA-SEA-ARS Southern Plains Watershed and Water Quality Laboratory. A general location map is shown in figure 1 and soil description given in table 1. Six flightlines were flown on May 1, 12, and 30, 1978. Two different approaches were used in soil moisture sampling.

Along flightline 6, two rows of samples were collected perpendicular to the flightline at the indicated locations. Figure 2 illustrates the spacing and layout of the eight points in the traverse moisture sampling scheme. Samples were obtained for the 0 to 2.5 cm, 2.5 to 5.0 cm, and the 5.0 to 15.0 cm depths. As shown in figure 1, each of these sites was located in proximity to a recording raingage. Table 2 lists the soil types and the land cover on each date. On flightlines 1 to 5 the data collected were on watershed units and soil moisture samples obtained generally on a grid.

Flightline 1 included 5 cropland or C watersheds (fig. 3, A). Descriptions of the land cover on these watersheds are given in table 3. Soil maps, sampling points and topography are presented in the Appendix. Soil descriptions are presented in table 1.

Flightlines 3 and 4 were flown over four rangeland or R watersheds (figure 3, B). Descriptions of the land cover of the R watersheds are listed in table 3. Soil maps, sampling sites and topography are presented in the Appendix. Soil descriptions are presented in table 1.
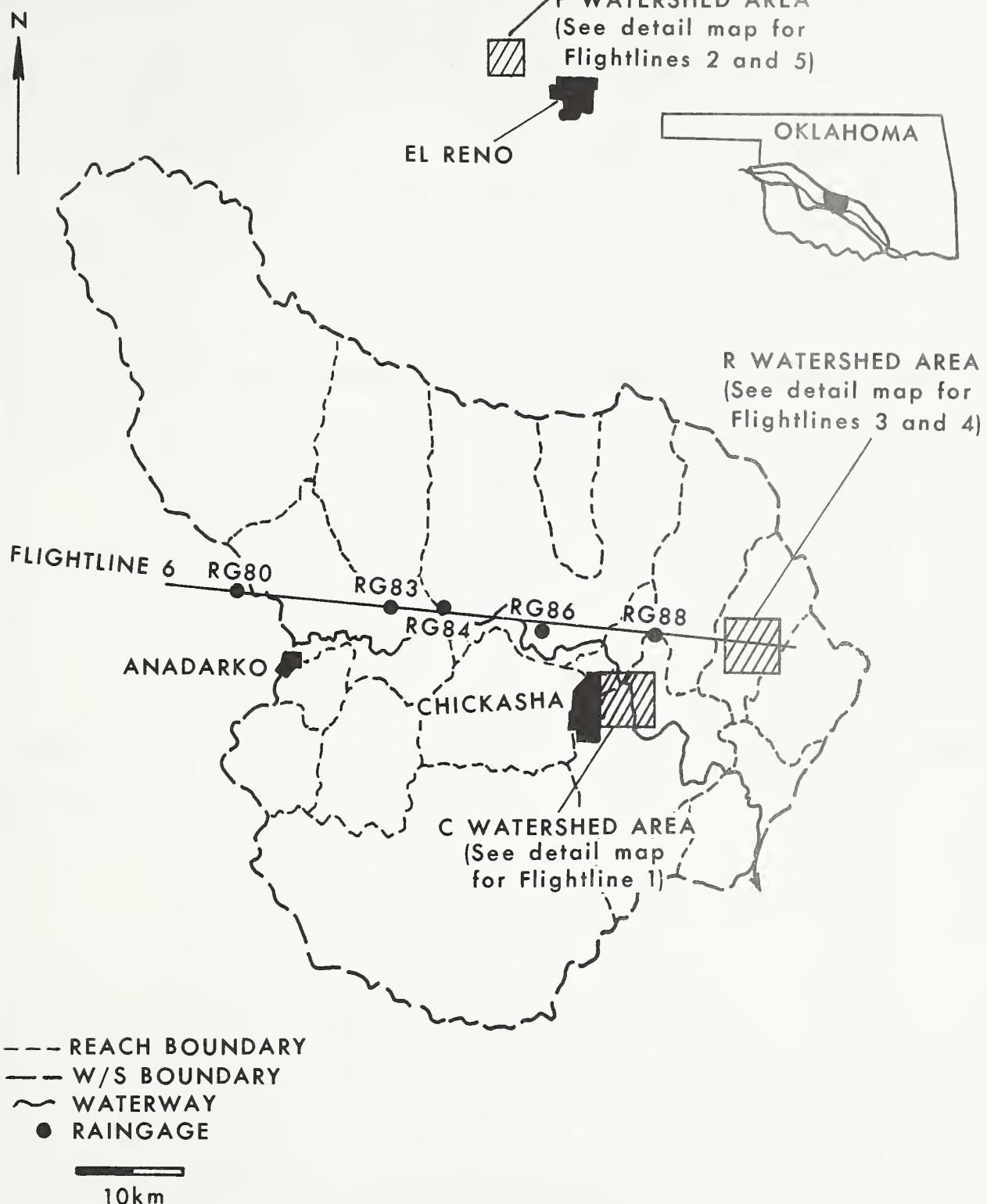
Figure 1.--General location map of the Washita River Experimental Watershed, Chickasha, Okla.

Table 1.—Chickasha, Okla., soils descriptions

| Soil type | Depth[1] | Internal drainage[2] and Permeability[3] | Location[4] | Available water capacity | Slope | Erosion |
|---|---|---|---|---|---|---|
| | | | | | Percent | |
| Aydelotte silt loam | D | M/SP | UP | – | – | No |
| Bethany silt loam | D | M/SP | UP | 0.18 to 0.22 | 0 to 1 | No |
| Cobb fine sandy loam | D | M/MP | UP | .14 | 3 to 5 | No |
| Dale silt loam | D | M/MP | FP | .15 to .24 | 0 to 1 | No |
| Grant Port complex | D | M/MP | UP | .15 to .20 | 0 to 12 | No |
| Kirkland silt loam | D | M/VSP | UP | .16 to .24 | 0 to 1 | No |
| McLain silt loam | D | M/MSP | FP | .15 to .22 | 0 to 1 | No |
| McLain silty clay loam | D | S/MSP | FP | – | 0 to 1 | No |
| Milan loam | D | M/MP | UP | – | – | No |
| Minco very fine sandy loam | D | M/MP | UP | .14 | 3 to 8 | No |
| Pond Creek silt loam | MD | M/MP | UP | .12 | 1 to 3 | Yes |
| Port silt loam | MD | M/MP | UP | .14 | 1 to 3 | No |
| Quinlan-Woodward complex | MD | S/SP | UP | .14 | 5 to 12 | No |
| Reinach silt loam | D | M/MP | FP | .13 to .24 | 0 to 1 | No |
| Renfrow silt loam | D | S/MP | UP | .15 to .24 | 2 to 5 | Yes |
| Teller loam | D | M/MP | UP | .12 to .16 | 2 to 5 | Yes |
| Zaneis loam | D | M/SP | UP | .11 to .20 | 2 to 5 | Yes |

[1] Depth codes: D=deep, MD=moderately deep.
[2] Internal drainage codes: S=slow, M=moderate.
[3] Permeability codes: VSP=very slow, SP=slow, MSP=moderately slow, MP=moderate.
[4] Location codes: FP=floodplain, UP=uplands.

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FLIGHT
DIRECTION

● SAMPLING POINT

60m    30m    30m    60m

● A    ● B    ● C    ● D

SITE ●

15m

● E    ● F    ● G    ● H
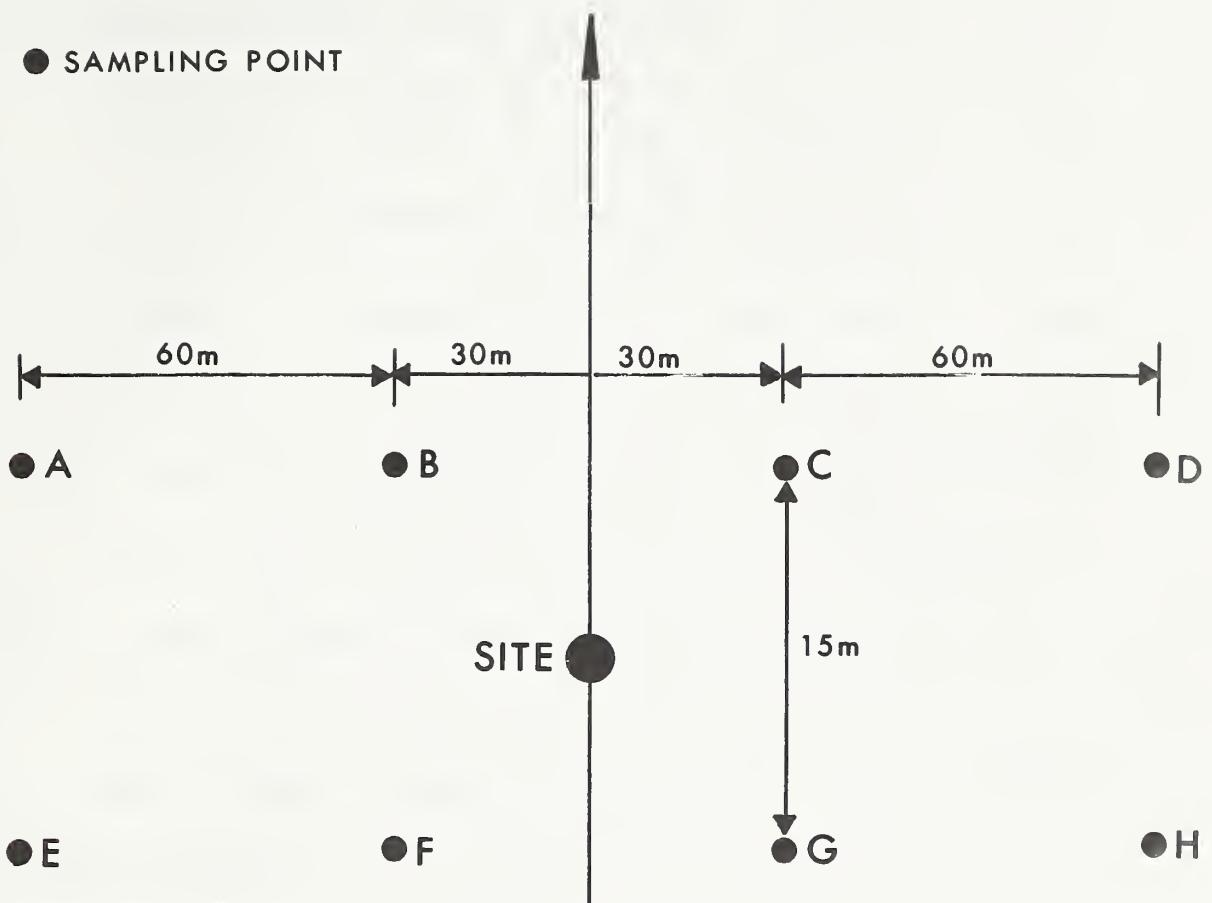
Figure 2.--Traverse soil moisture sampling scheme.

Table 2.--Chickasha, Okla., flightline 6 soil types land cover

| Site | Soil type | Land cover on -- | | |
| | | May 1, 1978 | May 12, 1978 | May 30, 1978 |
|------|-----------|-------------|--------------|--------------|
| RG80 | Cobb fine sandy loam | Alfalfa | Alfalfa | Alfalfa |
| RG83 | Pond Creek silt loam | Fallow | Fallow | Fallow |
| RG84 | Teller loam | Wheat | Wheat | Wheat |
| RG86 | Port silt loam | Pasture | Pasture | Pasture |
| RG88 | Grant Port complex | Fallow | Fallow | Fallow |

Table 3.--C and R watershed land cover, Chickasha, Olka.

| Watershed site | Land cover on -- | | |
| | May 1, 1978 | May 12, 1978 | May 30, 1978 |
|----------------|-------------|--------------|--------------|
| C3 | Fallow | Fallow | Fallow |
| C4 | Fallow | Fallow | Fallow |
| C5 | Winter wheat | Winter wheat | Winter wheat |
| C6 | Winter wheat | Winter wheat | Winter wheat |
| C8 | Alfalfa | Alfalfa | Fallow |
| R5 | Well managed pasture | Well managed pasture | Well managed pasture |
| R6 | Well managed pasture | Well managed pasture | Well managed pasture |
| R7 | Poorly managed pasture | Poorly managed pasture | Poorly managed pasture |
| R8 | Poorly managed pasture | Poorly managed pasture | Poorly managed pasture |
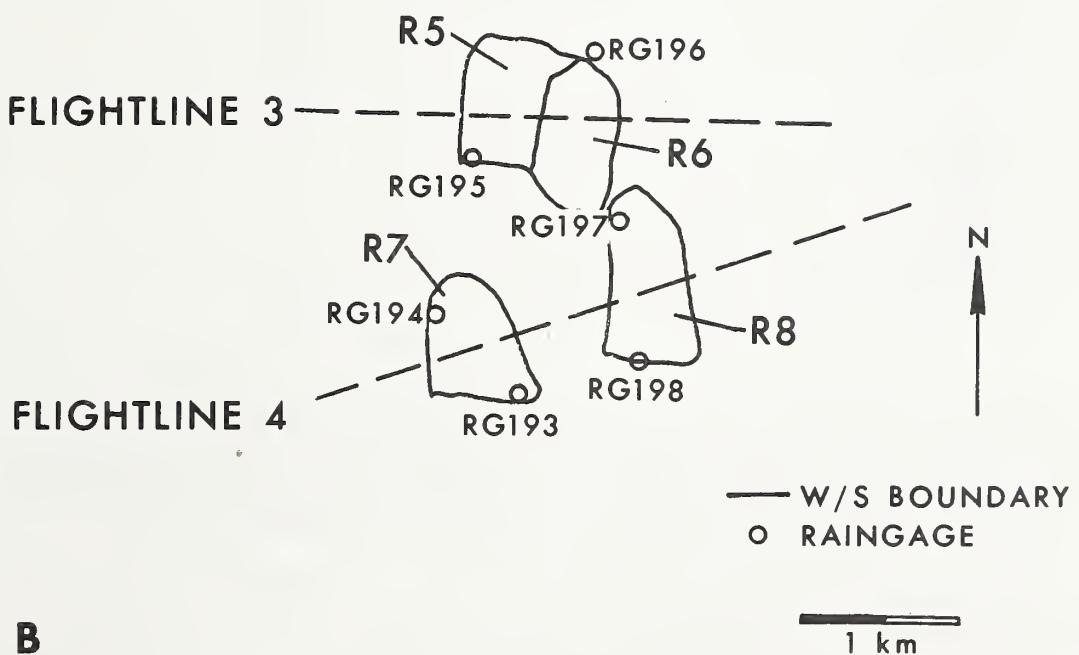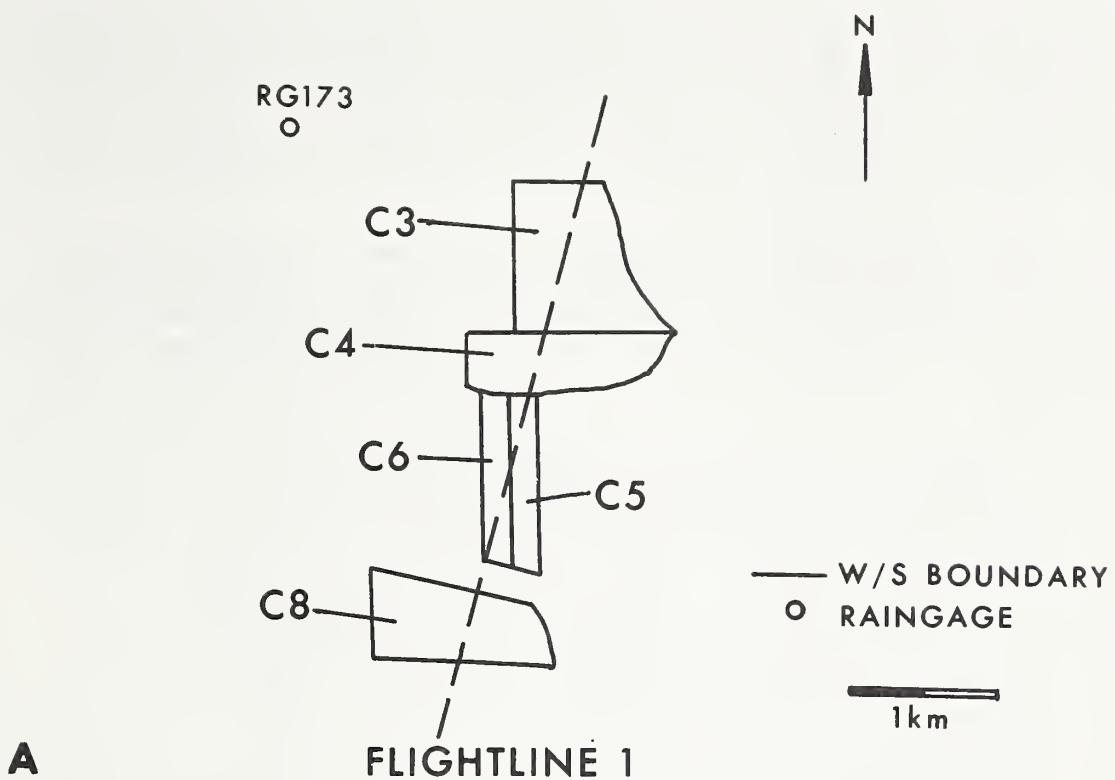
Figure 3.--Chickasha, Okla., watershed flightlines: <u>A</u>, C watershed area; <u>B</u>, R watershed area.

Flightlines 2 and 5 were flown over a group of eight watersheds located near El Reno, Okla., (fig. 4, A). These watersheds were all very small and for the purposes of this study were combined into two groups -- F1 and F2. All watersheds had a dense grass cover. Soils and sampling sites are presented in figure 4, A; soil descriptions in table 1. A topographic map of the area is shown in figure 4, B.

All soil moisture samples were weighed, oven-dried and weighed again to determine their gravimetric soil moisture. Bulk density samples from each field (table 4) were then used to determine the volumetric soil moisture. All samples were collected within $\pm$ 2 hours of the overflight and stored in oven cooking bags.

Table 4.--Bulk density of remote sensing soil
moisture sites, Chickasha, Okla.

| Site | Bulk density |
|------|--------------|
|  | $Gm/cm^3$ |
| C3 | 1.6 |
| C4 | 1.4 |
| C5 | 1.5 |
| C6 | 1.3 |
| C8 | 1.5 |
| F1 | 1.3 |
| F2 | 1.3 |
| R5 | 1.4 |
| R6 | 1.4 |
| R7 | 1.5 |
| R8 | 1.5 |
| RG80 | 1.3 |
| RG83 | 1.6 |
| RG84 | 1.3 |
| RG86 | 1.4 |
| RG88 | 1.6 |
| RG92 | 1.6 |

Climatological data were collected during the experimental period as part of the regular data collection program. Table 5 presents the pan evaporation, daily maximum and minimum air temperatures, and the daily rainfall at a number of gages. The gage locations are shown in figures 1, 3, and 4.

Riesel, Tex., test site

The study site located in the central part of Texas near Riesel was on an experimental watershed area operated by the USDA-SEA Grassland, Soil, and Water Laboratory. Fifteen sampling sites were identified along a 9 km
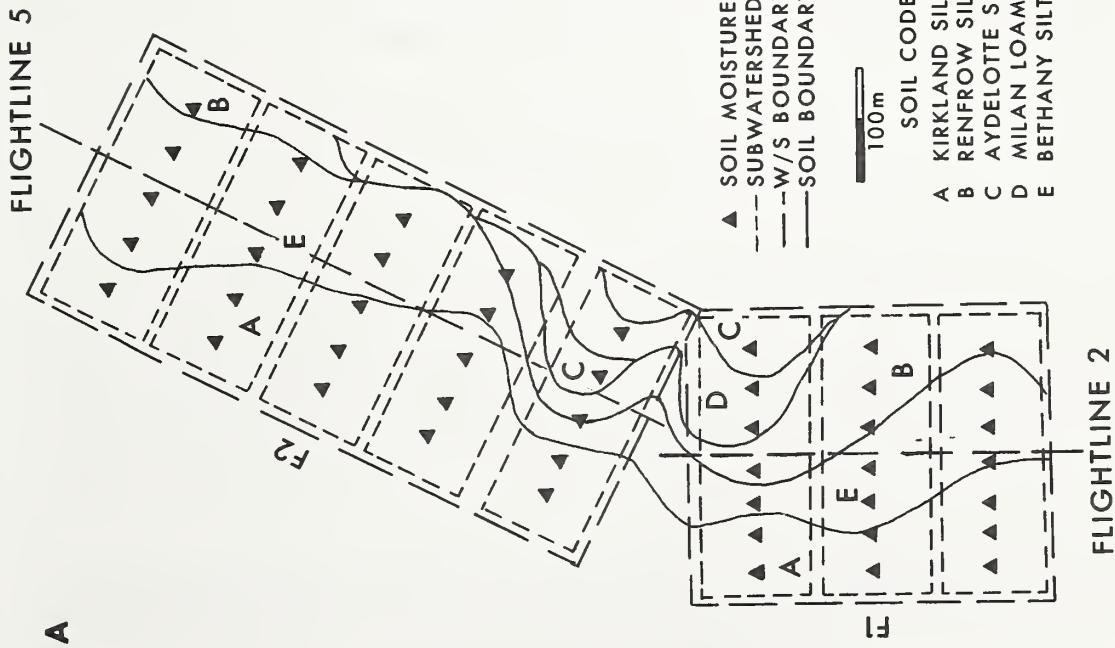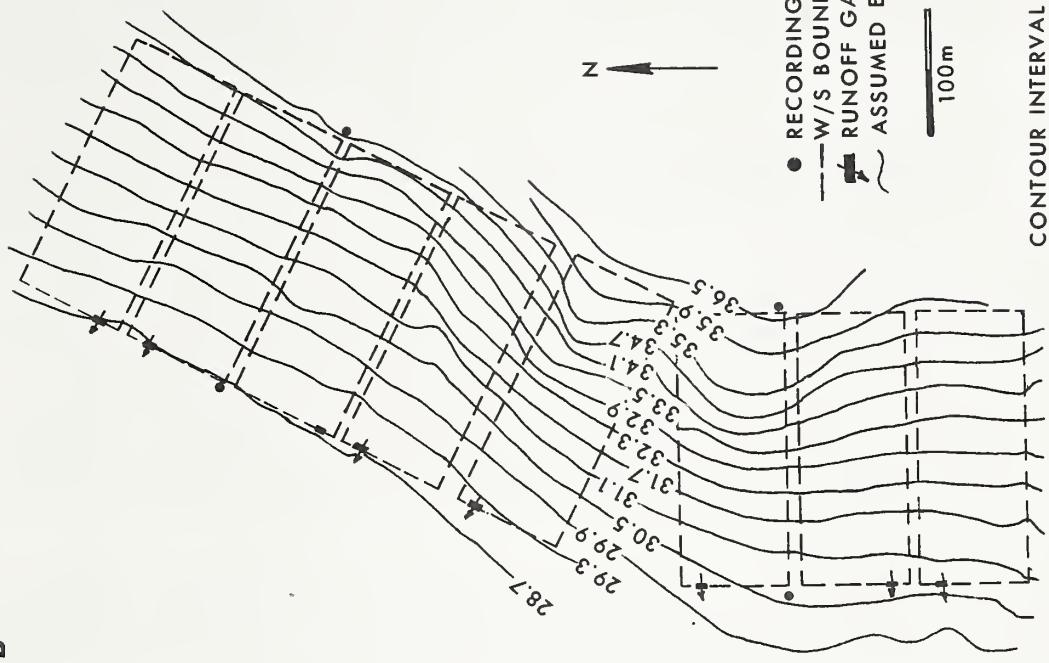
Figure 4.--F watershed area, El Reno, Okla.: A; Soils, sampling locations and flightlines; B, topographic map.

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Table 5.--Chickasha, Okla., climatological data

| DATE | PAN EVAP (CM) | DAILY TEMP MAX (DEG K) | DAILY TEMP MIN (DEG K) | RAINFALL AT RAINGAGE (CM) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 80 | 83 | 84 | 86 | 88 | 92 | 173 | 230 | 193 | 194 | 195 | 196 | 197 | 198 | 331 | 332 | 333 | 334 |
| 41678 | 0.28 | 300 | 287 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 41778 | .63 | 303 | 283 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 41878 | .66 | 300 | 280 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 41978 | .71 | 296 | 279 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42078 | .41 | 290 | 276 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42178 | .63 | 295 | 277 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42278 | .43 | 299 | 285 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42378 | .43 | 299 | 276 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42478 | .56 | 298 | 282 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42578 | .43 | 297 | 279 | .00 | .00 | .15 | .20 | .18 | .51 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42678 | .36 | 296 | 278 | .13 | .10 | .00 | 1.70 | .97 | .03 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42778 | .66 | 300 | 283 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .25 | .20 | .18 | .23 | .25 | .25 | .00 | .00 | .00 | .00 |
| 42878 | .28 | 300 | 286 | .13 | .00 | .00 | .00 | .00 | .00 | .36 | .38 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42978 | .20 | 303 | 288 | .38 | .00 | 2.51 | .00 | .00 | .36 | .89 | .84 | 1.30 | 1.32 | 1.40 | 1.40 | 1.30 | 1.27 | .38 | .41 | .36 | .38 |
| 43078 | .20 | 302 | 289 | 3.30 | 2.90 | 3.35 | 3.12 | 2.95 | 3.15 | 3.43 | 3.07 | 3.07 | 2.92 | 3.12 | 3.07 | 3.12 | 3.12 | 3.30 | 3.56 | 3.23 | 3.23 |
| 50178 | .28 | 294 | 283 | .15 | 3.10 | .23 | .08 | .10 | .25 | .00 | .00 | .05 | .05 | .05 | .03 | .05 | .08 | .20 | .36 | .38 | 3.30 |
| 50278 | .05 | 281 | 276 | .10 | .05 | .10 | .05 | .08 | .15 | .00 | .00 | .05 | .25 | .03 | .03 | .03 | .03 | .00 | .00 | .00 | .00 |
| 50378 | .15 | 288 | 277 | .05 | .13 | .08 | .23 | .13 | .46 | .46 | .51 | .28 | .13 | .23 | .25 | .25 | .25 | .00 | .00 | .00 | .46 |
| 50478 | .05 | 290 | 281 | .00 | .13 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50578 | .18 | 293 | 287 | .00 | .00 | .00 | .00 | .00 | .10 | .00 | .00 | .13 | .00 | .18 | .15 | .15 | .13 | .53 | .53 | .53 | .53 |
| 50678 | .08 | 296 | 282 | .00 | .00 | .00 | .00 | .23 | .00 | .08 | .05 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50778 | .30 | 298 | 280 | .00 | .13 | .25 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50878 | .28 | 298 | 279 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50978 | .30 | 300 | 282 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51078 | .61 | 307 | 290 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51178 | .51 | 306 | 280 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51278 | .46 | 300 | 281 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51378 | .46 | 306 | 285 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51478 | .46 | 303 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51578 | .51 | 303 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51678 | .30 | 298 | 290 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51778 | .20 | 306 | 290 | .00 | .00 | .00 | .05 | .13 | .00 | .00 | .00 | .00 | .18 | .00 | .00 | .00 | .00 | .25 | .00 | .00 | .00 |
| 51878 | .30 | 306 | 289 | 1.93 | 2.31 | 2.16 | 1.02 | 1.65 | .00 | .00 | 1.07 | .15 | .00 | .10 | .08 | .13 | .15 | .00 | .00 | .00 | .00 |
| 51978 | .05 | 305 | 288 | 1.12 | 1.88 | 1.22 | 2.67 | 2.08 | 2.87 | 1.37 | 2.49 | 2.44 | 2.26 | 2.21 | 2.03 | 2.18 | 2.31 | 6.60 | 6.60 | 6.07 | 5.84 |
| 52078 | .05 | 299 | 286 | .53 | 1.68 | 1.57 | 4.47 | 4.67 | 3.43 | 2.62 | 1.93 | 5.08 | 4.60 | 4.32 | 4.19 | 4.37 | 5.21 | 1.68 | 2.29 | .61 | 5.61 |
| 52178 | .43 | 303 | 289 | .18 | .38 | .43 | .00 | .00 | .00 | 1.47 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | 1.70 | 2.03 |
| 52278 | .56 | 304 | 290 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52378 | .51 | 304 | 290 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52478 | .43 | 304 | 290 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52578 | .56 | 304 | 289 | 1.52 | 2.34 | 2.34 | 1.78 | 1.60 | 2.03 | 1.88 | 1.70 | 1.90 | 1.90 | 2.03 | 1.88 | 1.90 | 1.98 | 1.35 | 1.50 | 1.37 | 1.37 |
| 52678 | .00 | 300 | 288 | 8.18 | 11.73 | 9.17 | 5.23 | 7.75 | 10.62 | 8.43 | 8.05 | 9.83 | 9.27 | 9.47 | 9.27 | 9.60 | 9.65 | 9.78 | 10.62 | 9.80 | 9.91 |
| 52778 | .00 | 297 | 288 | .03 | .38 | .53 | .30 | .38 | .53 | .58 | .97 | .71 | .63 | .69 | .76 | .43 | .58 | .30 | .28 | .30 | .33 |
| 52878 | .58 | 301 | 286 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52978 | .56 | 304 | 289 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 53078 | .56 | 304 | 289 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .10 | .08 | .10 | .10 |

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flightline. A map of the study area (fig. 5) shows the location of each sampling site. Flights were made on May 1, 12, and 30, 1978. All sites were sampled by using the scheme illustrated in figure 2, which involved 8 samples per site.

The land cover varied from almost bare soil to a very dense vegetative cover. Some sites experienced considerable vegetation growth between the first flight and the last flight. The soils and vegetation on each site and for each flight date are presented in table 6.

Along the flightline, the soils, characteristic of those in the Blackland Prairie of Texas, are deep, dense, slowly permeable, montmorillonitic clays with pronounced shrink-swell characteristics. General descriptions are given in table 7.

Gravimetric soil moisture samples were obtained at each site within $\pm$ 2 hours of the flight time on each of the three dates. At each location, soil samples of 200 to 1,000 gm were collected from the following depths: 0 to 2.5 cm, 2.5 to 5 cm, 5 to 10 cm, and 10 to 15 cm. Each sample was placed in a plastic bag and sealed for later weighing and analysis. The type and condition of the land cover was recorded at each location. The soil temperature at the 1 cm depth was recorded at selected locations.

The soil samples were weighed on the same day they were obtained. Over the next several days the samples were ovendried, the dry weights obtained, and the gravimetric water contents were computed. After the last flight date, soil bulk density samples were obtained by depths at each site. The bulk density for each site and each depth is given in table 8. The bulk densities were used to convert the gravimetric water contents to volumetric water contents.

Table 9 presents the pan evaporation, daily maximum and minimum temperatures, and the daily rainfall at each gage. The locations of the raingages in the immediate area of the sites are shown in figure 5.


## Remote Sensing Systems


The NASA 929 (C-130B) aircraft was the sensor platform used in these experiments. A nominal altitude of 305 m (1,000 ft) and a ground speed of 278 kilometers per hour, kph, (150 knots) were chosen. The systems used were: Color infrared photography, a modular multispectral scanner, a thermal infrared radiometer, multifrequency microwave radiometers, (a passive microwave scanner and multifrequency active microwave scatterometers).

Color infrared photography was obtained by using a Zeiss 23 cm (9 in) camera with Kodak 2443 film. A 15 cm (6 in) focal length at the specified altitude resulted in a nominal scale of approximately 1:2000 on the .photo products. Forward overlap of 10 percent was used.

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Figure 5.--General location map and soil moisture sampling sites, Riesel, Tex.

Table 6.--Soil type and land cover by site, Riesel, Tex., May 1, 12, and 30, 1978

| Site | Soil Type | Land cover on-- | | |
|---|---|---|---|---|
| | | May 1, 1978 | May 12, 1978 | May 30, 1978 |
| 1 | Houston black clay | Bermudagrass, 6 cm high, dense cover. | Bermudagrass, 10 to 15 cm high, dense cover. | Bermudagrass, 20 cm high, dense cover. |
| 2 | do. | Hardingrass, 5 cm high, very sparse stand. | Hardingrass and Johnsongrass, 5 to 10 cm, very sparse. | Hardingrass and Johnsongrass, 30 to 40 cm, sparse stand. |
| 3 | do. | Grain sorghum, 15 cm high, planted in 90 cm rows. | Grain sorghum, 30 cm high. | Grain sorghum, 50 to 60 cm high. |
| 4 | do. | Pasture-Bermudagrass, 10 cm high. | Pasture-Bermudagrass, 15 to 20 cm high. | Pasture-Bermudagrass, 20 cm high. |
| 5 | do. | Kliengrass, 30 cm high. | Kliengrass, 30 to 60 cm high. | Kliengrass, 90 cm high, headed. |
| 6 | do. | Native grass meadow, 45 cm high, very dense cover. | Native grass meadow, 30 to 50 cm high, very dense cover. | Native grass meadow, 30 to 50 cm high, very dense cover. |
| 7 | do. | Oats, 40 cm high, grazed. | Oats, 40 to 50 cm high. | Oats, harvested, stubble left. |
| 8 | do. | Grain sorghum, 15 cm high, planted in 90 cm rows. | Grain sorghum, 30 to 40 cm high. | Grain sorghum, 50 to 60 cm high. |
| 9 | Houston clay | Pasture-Bermudagrass, heavily grazed, 4 cm high. | Pasture-Bermudagrass, heavily grazed, 5 to 10 cm high. | Pasture-Bermudagrass, heavily grazed, 5 cm high. |
| 10 | Catalpa clay | Grass, 20 cm high under a tree canopy near a stream. | Grass, 40 to 50 cm high under a tree canopy near a stream. | Grass, 40 to 60 cm high under a tree canopy near a stream. |
| 11 | Wilson clay loam | Corn, 45 cm high. | Corn, 70 to 80 cm high. | Corn, 150 cm high. |
| 12 | Burleson Houston clay | Wheat, 90 cm high. | Wheat, 90 cm high, maturing. | Wheat, 90 cm high, matured. |
| 13 | do. | Wheat, 5 to 10 cm high, grazed. | Wheat, 5 to 15 cm high, grazed. | Wheat, 5 cm high, grazed. |
| 14 | Catalpa clay | Forage sorghum, 15 cm high. | Forage sorghum, 20 to 40 cm high. | Forage sorghum, 60 to 90 cm high. |
| 15 | Burleson Houston clay | Pasture, heavily grazed, grass, 15 cm high. | Pasture, heavily grazed, grass, 20 cm high. | Pasture, heavily grazed, grass, 15 to 30 cm high. |

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Table 7.--Riesel, Tex., soils descriptions.

| Soil type | Depth[1] | Internal drainage[2] and Permeability[3] | Location[4] | Available water capacity | Slope | Erosion |
|-----------|----------|-------------------------------------------|-------------|--------------------------|-------|---------|
| | | | | | Percent | |
| Burleson-Houston clay | D | S/VSP | UP | 0.05 | 1 to 3 | No |
| Calalpa clay | MD | M/SP | FP | - | 0 to 1 | No |
| Houston Black clay | D | S/MP | UP | .05-.08 | 1 to 4 | No |
| Houston clay | MD | S/MP | UP | .05-.10 | 1 to 4 | No |
| Wilson clay loam | D | S/VSP | UP | .05-.10 | 0 to 1 | No |

[1] Depth codes: D=deep, MD=moderately deep.
[2] Internal drainage codes: S=slow, M=moderate.
[3] Permeability codes: VSP=very slow, SP=slow, MSP=moderately slow, MP=moderate.
[4] Location codes: FP=floodplain, UP=uplands.


Table 8.--Bulk density of soil samples by depth, Riesel, Tex.

| Site | Soil samples collected at depth of-- | | | |
|------|-----------|-------------|-----------|------------|
| | 0 to 2.5 cm | 2.5 to 5 cm | 5 to 10 cm | 10 to 15 cm |
| | $Gm/cm^3$ | | | |
| 1 | 1.2 | 1.4 | 1.5 | 1.5 |
| 2 | 1.1 | 1.4 | 1.4 | 1.6 |
| 3 | 1.2 | 1.5 | 1.4 | 1.5 |
| 4 | 1.1 | 1.3 | 1.4 | 1.5 |
| 5 | 1.3 | 1.4 | 1.4 | 1.4 |
| 6 | 1.0 | 1.2 | 1.2 | 1.3 |
| 7 | 1.2 | 1.2 | 1.3 | 1.3 |
| 8 | 1.2 | 1.5 | 1.4 | 1.5 |
| 9 | 1.4 | 1.4 | 1.5 | 1.6 |
| 10 | 1.3 | 1.3 | 1.4 | 1.4 |
| 11 | 1.1 | 1.4 | 1.4 | 1.5 |
| 12 | 1.1 | 1.2 | 1.2 | 1.3 |
| 13 | 1.1 | 1.2 | 1.2 | 1.3 |
| 14 | 1.2 | 1.4 | 1.4 | 1.6 |
| 15 | 1.5 | 1.7 | 1.6 | 1.6 |

Table 9.--Riesel, Tex., climatological data

| DATE | PAN EVAPORATION (CM) | DAILY TEMPERATURE | | RAINFALL AT RAINGAGE (CM) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MAX (DEG K) | MIN (DEG K) | 5 | 20 | 26A | 56A | 69 | 69B | 75A | 89 | W6 |
| 41648 | 0.71 | 298 | 289 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 41778 | .74 | 299 | 289 | .13 | .15 | .10 | .18 | .15 | .15 | .25 | .20 | .18 |
| 41878 | .13 | 298 | 284 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 41978 | 1.04 | 299 | 285 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42078 | .97 | 295 | 280 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42178 | .46 | 294 | 281 | .15 | .08 | .10 | .13 | .18 | .25 | .41 | .36 | .51 |
| 42278 | .94 | 297 | 285 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42378 | .05 | 295 | 286 | .05 | .15 | .25 | .25 | .20 | .15 | .23 | .20 | .10 |
| 42478 | .66 | 300 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42578 | .13 | 303 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42678 | 1.30 | 296 | 281 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42778 | .43 | 296 | 287 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42878 | 1.12 | 299 | 285 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 42978 | 1.04 | 300 | 289 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 43078 | .46 | 300 | 292 | .79 | .48 | .06 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50178 | .66 | 302 | 288 | 2.01 | 2.59 | 2.26 | 2.18 | 2.08 | 1.90 | 2.57 | 2.03 | 2.06 |
| 50278 | .69 | 301 | 282 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50378 | 1.27 | 292 | 280 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50478 | .33 | 289 | 281 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50578 | .58 | 294 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50678 | .89 | 302 | 294 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50778 | .20 | 299 | 291 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50878 | .13 | 304 | 287 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 50978 | .58 | 302 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51078 | .74 | 302 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51178 | .84 | 303 | 291 | .28 | .20 | .18 | .71 | .46 | .36 | .38 | .30 | .20 |
| 51278 | .58 | 300 | 291 | .28 | .25 | .56 | .76 | .81 | .76 | .89 | .76 | .41 |
| 51378 | 1.47 | 306 | 286 | .00 | .46 | .81 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51478 | 1.02 | 300 | 286 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51578 | 1.09 | 305 | 288 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51678 | 1.09 | 306 | 291 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51778 | .94 | 304 | 294 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51878 | .71 | 305 | 294 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 51978 | .79 | 306 | 294 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52078 | .97 | 301 | 292 | 2.44 | 2.59 | 1.96 | 2.16 | 2.08 | 2.06 | 2.26 | 2.11 | 2.06 |
| 52178 | .81 | 302 | 292 | 1.04 | 1.55 | 1.27 | 1.27 | 1.37 | 1.30 | 1.65 | 1.42 | 1.45 |
| 52278 | .20 | 304 | 292 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52378 | .74 | 304 | 293 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52478 | .56 | 303 | 292 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52578 | .76 | 305 | 292 | .51 | .30 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52678 | .79 | 304 | 292 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52778 | 1.40 | 304 | 295 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52878 | .76 | 305 | 294 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 52978 | .53 | 304 | 294 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 53078 | 1.19 | 304 | 292 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

The modular multispectral scanner (MMS) used on the NASA 929 senses visible and infrared energy in 11 spectrometer channels or bands (table 10). The scanner has a total field of view of 100° and an instantaneous field of view of 2.5 mrad (milliradians) for each band. This system was flown at an altitude of 610 m (2,000 ft) at which the ground resolution element was approximately 5 m (16 ft).

Table 10.--Modular multispectral scanner
wavelength bands

| Band | Wavelength | | Peak Output |
| | Low | High | |
| --- | --- | --- | --- |
| | -----------------um----------------- | | |
| 1 | 0.419 | 0.456 | 0.442 |
| 2 | .458 | .500 | .481 |
| 3 | .502 | .545 | .522 |
| 4 | .546 | .583 | .563 |
| 5 | .584 | .621 | .598 |
| 6 | .622 | .662 | .641 |
| 7 | .662 | .701 | .682 |
| 8 | .703 | .747 | .727 |
| 9 | .770 | .863 | .789 |
| 10 | .959 | 1.039 | .981 |
| 14 | 8.000 | 12.080 | 8.100 |

Thermal infrared radiometer data were also obtained by using a Barnes precision radiation thermometer (PRT5) with a spectral range from 8 to 14 microns. This is a fixed beam sensor with a field view of 2°. The ground swath width at the flight altitude was 24 m (79 ft).

The multifrequency microwave radiometer (MFMR) is a collection of 5 separate radiometers operating over the frequency range of from 1.414 to 37 GHz. The characteristics of these radiometers are described in table 11. Since the L and C band radiometers shared a rotatable mount in the nose of the aircraft only one was usable at a particular time. They also operate through a dielectric radome which contributes to the calibration problems for these radiometers. The three K band radiometers operate through the open cargo door at the rear of the aircraft. The instruments are basically Dieke radiometers in which the incoming radiation is compared with internal reference sources at known temperatures to obtain the quantitative values of the brightness temperature of the incoming radiation.

The swath widths listed in table 11 are for the 3 dB or half power points of the antenna pattern. This means for the L-Band system at ± 7.5° off from the beam center the sensitivity is one-half that at the beam center. The first nulls or minimums in the antenna pattern are generally 2.5 times further out producing a beam width between nulls, called the main beam, of 37.5° for

L-Band and 15° for the others.  Generally over 90 percent of the energy received by the radiometer comes through the main beam and of that energy 60 to 65 percent is received within the 3 dB points.

Table 11.--Passive microwave sensor systems

| System designation | Center frequency | Wavelength | Receiver bandwidth | Antenna beamwidth | Swath width for 305 m altitude | |
|---|---|---|---|---|---|---|
| | | | | | 0° look angle | 40° look angle |
| | GHz | Cm | MHz | Degrees | M | M |
| L band | 1.41 | 21.00 | 27 | 15 | 75 | 120 |
| C band | 5.00 | 6.00 | 50 | 6 | 30 | 50 |
| Ku band | 18.00 | 1.67 | 200 | 6 | 30 | 50 |
| K band | 22.00 | 1.35 | 200 | 6 | 30 | 50 |
| Ka band | 37.00 | .81 | 200 | 6 | 30 | 50 |

Look angles of 0° and 40° were used for the C, L, and K band radiometers.  A forward look angle was used for the C and L bands, and a backward look angle for the K bands.  Horizontal and vertical polarization data were collected for the C and K bands and only horizontal polarization data for the L band.

The passive microwave imaging system (PMIS), a scanning radiometer sensing at a 2.8 cm wavelength, consisted of three basic components:  a phased array antenna, a beam steering computer, and the microwave receivers for the horizontal and vertical channels.  The antenna is a dual polarized, electrically scanned, phased array which consists of 51 linear slotted waveguide sections forming a 109 by 91 cm aperture.  The magnitudes of the resulting brightness temperatures are determined by comparison with internal blackbodies at 323 K and 403 K.

The data for the 2.8 cm scanning radiometer were recorded at 44 beam positions for each scan.  The scan rate was adjusted to provide contiguous coverage, which for the altitude and velocity of these flights was one scan per second.  A backward look angle of approximately 49.2° was used for this sensor.  The ground resolution element is approximately 21 by 34 m (69 by 112 ft).

During missions over Oklahoma and Texas, three scatterometers were on the aircraft operating at frequencies listed in table 12.  Data for HH and HV polarizations were available.  The scatterometer antenna pattern is fan-shaped which covers the 0 range, along the aircraft flight path of approximately 5° to 60° for the radar direction.  The scatterometer receives the backscattered signal at all angles of incidence simultaneously.  As a result of the aircraft's forward motion, different Doppler frequency shifts are introduced in the return signals for different incidence angles.

Table 12. --Scatterometer frequencies

| System designation | Frequency | Wavelength |
|---|---|---|
| | GHz | Cm |
| C band | 4.75 | 6.3 |
| L band | 1.60 | 18.9 |
| P band | .40 | 74.9 |

The ground spot sizes of the scattermeter data are processed to approximately 35 m along track using the Doppler information for all three frequencies. The cross-track resolution is mainly based on the beamwidth for each individual instrument. When the aircraft altitude is 450 m the cross-track spot size is 50 m for the C band, 70 m for the L band, and 110 m for the P band.

Table 13 summarizes the systems and data collected. Additional details on data preparation and processing are presented in the next section.

Table 13.--System run numbers

| System | Operating during runs (look angle) |
|---|---|
| Photography | 1,2,3,4,5 |
| PRT5 | 1,2,3,4,5 |
| L band | 2 (0°), 4(40°) |
| C band | 3(0°), 5(40°) |
| K bands | 2(0°), 3(0°), 4(40°), 5(40°) |
| PMIS | 2,3,4,5 |
| Scatterometers | 1 |

## DATA AND PROCESSING
### Soil Moisture Observations

Gravimetric soil moistures were converted to percent by volume by using the bulk density values. Samples collected within each site at each depth are summarized in table 14. If for some reason remote sensing measurements were not obtained at a site or if they were not reliable, the soil moisture data were not included in table 14.

Table 14.--Soil moisture observations

| | | VOLUMETRIC SOIL MOISTURE (%) | | | | | |
| | | 0 - 2.5 CM DEPTH | | 2.5 - 5 CM DEPTH | | 5 - 15 CM DEPTH | |
| DATE | SITE | MEAN | STANDARD DEVIATION | MEAN | STANDARD DEVIATION | MEAN | STANDARD DEVIATION |
|---|---|---|---|---|---|---|---|
| 50178 | C3 | 0.300 | 0.032 | 0.260 | 0.033 | 0.276 | 0.032 |
| 50178 | C4 | .306 | .045 | .272 | .035 | .280 | .038 |
| 50178 | C5C6 | .283 | .041 | .250 | .039 | .149 | .042 |
| 50178 | F1 | .236 | .066 | .152 | .031 | .136 | .038 |
| 50178 | RG83 | .274 | .055 | .237 | .027 | .220 | .033 |
| 50178 | RG88 | .267 | .033 | .206 | .032 | .129 | .038 |
| 50178 | R5 | .307 | .059 | .243 | .050 | .156 | .041 |
| 50178 | R6 | .319 | .046 | .258 | .041 | .169 | .040 |
| 50178 | R7 | .284 | .043 | .232 | .051 | .191 | .058 |
| 50178 | R8 | .323 | .070 | .274 | .055 | .203 | .061 |
| 50178 | TX 3 | .240 | .093 | .349 | .069 | .386 | .030 |
| 50178 | TX 4 | .175 | .027 | .238 | .024 | .279 | .019 |
| 51278 | C3 | .140 | .046 | .254 | .058 | .306 | .052 |
| 51278 | C4 | .167 | .088 | .230 | .042 | .266 | .063 |
| 51278 | C5C6 | .192 | .053 | .221 | .046 | .218 | .040 |
| 51278 | F1 | .286 | .027 | .237 | .023 | .228 | .028 |
| 51278 | F2 | .253 | .029 | .225 | .023 | .223 | .020 |
| 51278 | RG83 | .042 | .009 | .105 | .025 | .135 | .029 |
| 51278 | RG88 | .115 | .047 | .165 | .030 | .208 | .048 |
| 51278 | R5 | .220 | .068 | .194 | .042 | .201 | .027 |
| 51278 | R6 | .226 | .068 | .202 | .029 | .210 | .017 |
| 51278 | R7 | .184 | .036 | .219 | .044 | .250 | .031 |
| 51278 | R8 | .189 | .076 | .218 | .043 | .248 | .040 |
| 51278 | TX 3 | .159 | .047 | .348 | .045 | .392 | .017 |
| 51278 | TX 4 | .210 | .014 | .257 | .022 | .287 | .021 |
| 51278 | TX 8 | .239 | .021 | .343 | .034 | .367 | .029 |
| 51278 | TX 9 | .274 | .024 | .206 | .040 | .199 | .053 |
| 51278 | TX10 | .280 | .056 | .222 | .057 | .208 | .053 |
| 51278 | TX11 | .091 | .016 | .150 | .031 | .265 | .027 |
| 51278 | TX12 | .112 | .019 | .134 | .016 | .128 | .016 |
| 51278 | TX13 | .114 | .011 | .152 | .013 | .178 | .019 |
| 51278 | TX15 | .182 | .025 | .212 | .019 | .225 | .011 |
| 53078 | C3 | .286 | .090 | .323 | .058 | .315 | .032 |
| 53078 | C4 | .224 | .053 | .311 | .066 | .310 | .037 |
| 53078 | C5C6 | .334 | .086 | .347 | .067 | .356 | .066 |
| 53078 | F1 | .537 | .079 | .424 | .065 | .348 | .053 |
| 53078 | F2 | .509 | .043 | .382 | .036 | .331 | .025 |
| 53078 | RG83 | .264 | .132 | .224 | .053 | .223 | .035 |
| 53078 | RG88 | .404 | .065 | .291 | .025 | .285 | .011 |
| 53078 | R5 | .437 | .083 | .335 | .051 | .313 | .025 |
| 53078 | R6 | .412 | .098 | .324 | .042 | .303 | .034 |
| 53078 | R7 | .289 | .034 | .287 | .029 | .292 | .022 |
| 53078 | R8 | .341 | .093 | .305 | .037 | .299 | .033 |
| 53078 | TX 3 | .220 | .019 | .362 | .035 | .358 | .026 |
| 53078 | TX 4 | .142 | .016 | .214 | .011 | .253 | .010 |
| 53078 | TX 8 | .116 | .028 | .287 | .050 | .339 | .059 |
| 53078 | TX 9 | .102 | .011 | .162 | .029 | .214 | .043 |
| 53078 | TX10 | .133 | .056 | .168 | .061 | .180 | .057 |
| 53078 | TX11 | .047 | .021 | .136 | .035 | .199 | .035 |
| 53078 | TX12 | .065 | .018 | .142 | .048 | .201 | .027 |
| 53078 | TX13 | .085 | .009 | .145 | .023 | .186 | .069 |
| 53078 | TX15 | .157 | .029 | .214 | .027 | .214 | .017 |

Table 15.--NERDAS data

| TIME | LAT | LONG | ALT | TAS | HDG | DRIFT | ROLL | PITCH | GDS | VTACC | WDS | WD< | DTTG | TTG | CTD | DTK | TRK< | FRAME |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18:53:55.5 | +34'59.4 | -097'55.5 | 00,960 | 158 | 014.2 | -03.1 | +01.4 | -00.2 | 149 | +0.98 | 013 | 056 | 0006.4 | 002.6 | 000.5 | 027.5 | -000.3 | 136 |
| 18:54:00.5 | +34'59.6 | -097'55.4 | 00,980 | 159 | 014.4 | -02.8 | -01.7 | +00.2 | 150 | +0.98 | 012 | 051 | 0006.3 | 002.5 | 000.5 | 027.5 | +000.4 | 137 |
| 18:54:05.5 | +34'59.9 | -097'55.3 | 00,980 | 159 | 012.6 | -02.2 | -02.6 | +00.1 | 150 | +1.17 | 012 | 044 | 0006.1 | 002.4 | 000.5 | 027.5 | -000.5 | 138 |
| 18:54:10.5 | +35'00.0 | -097'55.3 | 00,980 | 159 | 012.1 | -02.0 | +00.5 | +00.1 | 150 | +0.98 | 012 | 046 | 0005.8 | 002.3 | 000.4 | 027.5 | -001.6 | 139 |
| 18:54:15.5 | +35'00.1 | -097'55.2 | 01,020 | 159 | 012.0 | -02.9 | -00.9 | -00.3 | 151 | +1.19 | 013 | 050 | 0005.6 | 002.2 | 000.3 | 027.5 | -001.8 | 140 |
| 18:54:20.5 | +35'00.4 | -097'55.2 | 01,050 | 159 | 012.4 | -03.3 | +01.3 | +00.5 | 152 | +1.19 | 013 | 062 | 0005.5 | 002.2 | 000.4 | 027.5 | -001.6 | 141 |
| 18:54:25.5 | +35'00.6 | -097'55.2 | 01,040 | 161 | 012.3 | -02.4 | +00.2 | +00.4 | 151 | +1.19 | 011 | 041 | 0005.1 | 002.0 | 000.4 | 027.5 | -000.7 | 142 |
| 18:54:30.5 | +35'00.9 | -097'55.1 | 01,050 | 161 | 011.7 | -00.8 | +00.2 | +00.4 | 150 | +1.16 | 012 | 025 | 0005.0 | 002.0 | 000.5 | 027.5 | -000.6 | 143 |
| 18:54:35.5 | +35'01.1 | -097'55.1 | 01,060 | 160 | 012.7 | -01.8 | +03.7 | -00.2 | 150 | +1.19 | 013 | 036 | 0004.8 | 001.9 | 000.4 | 027.5 | -000.5 | 144 |
| 18:54:40.6 | +35'01.3 | -097'55.1 | 01,050 | 159 | 016.0 | -03.4 | -00.7 | +01.1 | 150 | +1.13 | 015 | 054 | 0004.6 | 001.8 | 000.5 | 027.5 | +001.3 | 145 |
| 18:54:45.6 | +35'01.5 | -097'54.8 | 01,040 | 160 | 013.8 | -02.1 | -05.1 | +00.5 | 149 | +0.95 | 014 | 037 | 0004.3 | 001.8 | 000.3 | 027.5 | +000.7 | 146 |
| 18:54:50.6 | +35'01.6 | -097'55.3 | 01,040 | 158 | 011.6 | -03.1 | +02.6 | +00.2 | 148 | +0.91 | 012 | 050 | 0004.2 | 001.7 | 000.5 | 027.5 | +000.0 | 147 |
| 18:54:55.6 | +35'01.9 | -097'54.8 | 01,060 | 159 | 011.9 | -01.9 | -00.7 | -00.1 | 147 | +1.10 | 012 | 035 | 0003.7 | 001.6 | 000.5 | 027.5 | +000.5 | 148 |
| 18:55:00.6 | +35'02.1 | -097'54.7 | 01,070 | 160 | 011.7 | -02.8 | -01.0 | -00.2 | 148 | +0.79 | 013 | 031 | 0003.5 | 001.5 | 000.5 | 027.5 | -001.0 | 149 |
| 18:55:05.6 | +35'02.3 | -097'54.7 | 01,060 | 159 | 012.1 | -02.9 | +01.5 | +00.1 | 149 | +1.16 | 014 | 037 | 0003.2 | 001.4 | 000.5 | 027.5 | -001.5 | 150 |
| 18:55:10.6 | +35'02.6 | -097'54.7 | 01,060 | 159 | 012.0 | -02.3 | +01.0 | -00.2 | 149 | +0.98 | 013 | 046 | 0003.2 | 001.3 | 000.5 | 027.5 | -002.0 | 151 |
| 18:55:15.5 | +35'02.7 | -097'54.7 | 01,050 | 159 | 012.3 | -02.9 | +01.7 | +00.2 | 149 | +1.14 | 013 | 042 | 0003.0 | 001.2 | 000.5 | 027.5 | -001.4 | 152 |
| 18:55:20.6 | +35'02.9 | -097'54.6 | 01,050 | 159 | 012.5 | -02.5 | +01.7 | +00.5 | 150 | +0.98 | 012 | 039 | 0002.8 | 001.1 | 000.4 | 027.5 | -001.0 | 153 |
| 18:55:25.6 | +35'03.2 | -097'54.6 | 01,050 | 159 | 013.5 | -02.5 | +00.8 | +00.6 | 150 | +0.95 | 012 | 050 | 0002.8 | 001.1 | 000.5 | 027.5 | +000.0 | 154 |
| 18:55:30.6 | +35'03.3 | -097'54.5 | 01,040 | 158 | 013.5 | -01.8 | +00.8 | +00.3 | 149 | +0.95 | 013 | 040 | 0002.4 | 001.8 | 000.4 | 027.5 | +000.6 | 155 |

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Five runs were made on each of the flightlines on May 1, 1978. On May 12 and May 30, 1978, only runs 2 and 4 were made on flightline 6 at Chickasha, Okla. The aircraft encountered several problems in locating some sites; consequently, no remote sensing data were obtained. Also, errors in judgment on the selection of test sites resulted in the deletion of sites.

All data were preprocessed by the NASA Johnson Space Center and supplied to the NASA Goddard Space Flight Center and the USDA-SEA-AR Hydrology Laboratory for further processing. An important part of this additional processing was the time location of sensor coverage of each site. This was done by using the Navigational Engineering Recording Data Analysis System (NERDAS) data which related photo center times to instrument recording times. An example of the NERDAS data is shown in table 15. By locating the field or site boundaries on the photos, the start and stop times of sensor coverage were determined. This section describes the procedures used for time locating each sensor system and presents the sensor data.

## Color infrared photography

NERDAS data included the frame center time for each photo as well as distortion parameters, altitude and ground speed. Although constant altitude and ground speed and zero distortion were desired, there were variations. Distortions were considered minor and no correction was made for these. Photo scales for the 23 cm (9 in) products for various altitudes are listed in table 16.

Table 16.--Photo scale-altitude relationships

| Altitude | Scale |
|----------|-------|
| M | |
| 245 ------------------------------------ | 1:1600 |
| 275 ------------------------------------ | 1:1800 |
| 305 ------------------------------------ | 1:2000 |
| 335 ------------------------------------ | 1:2200 |
| 365 ------------------------------------ | 1:2400 |

## Modular multispectral scanner

The modular multispectial scanner (MMS) was operated only on May 30, 1978, over flightlines 1 and 3 at Chickasha, Okla. at an altitude of 610 m (2,000 ft). Raw data were only processed for flightline 1. Gray scale imagery for each of the channels is shown in figure 6.


## Thermal infrared radiometer

Data collected by the precision thermal radiometer (PRT5) sensor were averaged for the time frames of sensor coverage. In most cases several sets of data collected during different runs were averaged for each site. Table 17 lists temperatures and soil temperatures measured by the ground observers in the top 2.5 cm (1 in).


## K band radiometers

Data obtained at $0^o$ can be related to the photos by using the photo center times, altitudes, and ground speeds listed on the NERDAS printout, not the photo clock times. To determine the time frame of $0^o$ coverage of a particular line-run-site-day combination, the NERDAS printout for the line, run and day is used to identify the film roll. The frames that cover the site are then located and the photo distance from the starting photo center to the beginning of the site is measured. Next, the distance from the last photo center to the end of the site is measured. Distances measured in the flight direction are positive and distances in the opposite direction are negative.

Photo center times of the first and last coverage frames as well as the altitude and ground speed are determined. For each of the frames the ground speed in meters per second is computed. Next, the scale of each photo is determined. This is the conversion from centimeters to meters and is computed by dividing the altitude in meters by the focal length in centimeters. In this case the focal length is 15.25 cm (6 in).

The start and stop times are then determined by multiplying the scale factor in m/cm by the distance in centimeters measured off the photo and then dividing by the ground speed in m/sec. This correction is applied to the photo center time. Typical values are listed in table 18.

In order to use the $40^o$ look angle data, a time correction must be applied to the start and stop-degree times determined following the zero-degree procedure. This is necessary because the sensor covers the location on a photo after the camera does. The system geometry is shown in figure 7, A. The distance behind the NASA 929 plane is called S and depends on the altitude (H) as described in the following equation:

$$S = 0.8391 * H \qquad (1)$$

1 MILE
1.61 KM

CHANNEL 1
.41-.45 MICRONS

CHANNEL 2
.45-.5 MICRONS

CHANNEL 3
.5-.54 MICRONS

CHANNEL 4
.54-.58 MICRONS

CHANNEL 5
.58-.62 MICRONS
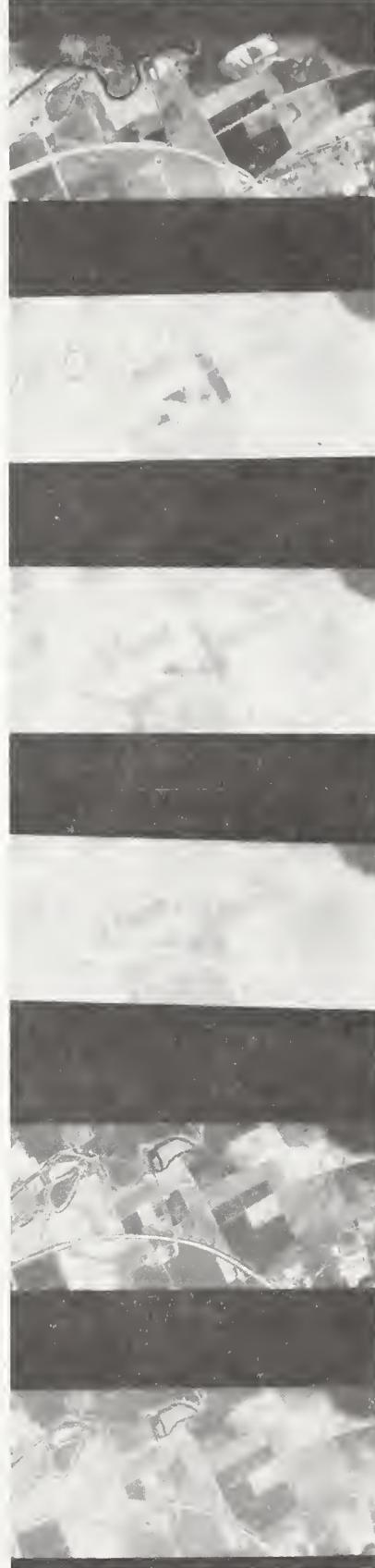
CHANNEL 6
.62-.66 MICRONS

CHANNEL 7
.66-.7 MICRONS

CHANNEL 8
.7-.74 MICRONS

CHANNEL 9
.77-.86 MICRONS

CHANNEL 10
.95-1.03 MICRONS

CHANNEL 11
10-12.5 MICRONS

Figure 6.--Multispectral scanner imagery, Chickasha, Okla., flightline 1, May 30, 1978.

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Table 17.--Temperature observations

| DATE | SITE | SOIL TEMPERATURE | PRT5 TEMPERATURE |
|------|------|------------------|------------------|
| | | --------DEG K------- | |
| 50178 | C3 | 293.6 | 296.7 |
| 50178 | C4 | 291.9 | 296.8 |
| 50178 | C5C6 | 296.2 | 295.2 |
| 50178 | F1 | 290.9 | 289.5 |
| 50178 | RG83 | 295.5 | 291.6 |
| 50178 | RG88 | 300.2 | 294.9 |
| 50178 | R5 | 293.4 | 298.3 |
| 50178 | R6 | 295.4 | 298.7 |
| 50178 | R7 | 295.3 | 294.6 |
| 50178 | R8 | 295.1 | 294.5 |
| 50178 | TX 3 | 300.0 | - |
| 50178 | TX 4 | 291.0 | - |
| 51278 | C3 | 296.9 | 299.0 |
| 51278 | C4 | 296.8 | 300.2 |
| 51278 | C5C6 | 294.7 | 296.0 |
| 51278 | F1 | 292.4 | - |
| 51278 | F2 | 293.6 | - |
| 51278 | RG83 | 295.8 | 299.0 |
| 51278 | RG88 | 298.7 | 299.4 |
| 51278 | R5 | 294.5 | 301.6 |
| 51278 | R6 | 295.6 | 302.0 |
| 51278 | R7 | 297.3 | 300.5 |
| 51278 | R8 | 295.8 | 301.4 |
| 51278 | TX 3 | 307.0 | 313.3 |
| 51278 | TX 4 | 307.0 | 313.0 |
| 51278 | TX 8 | 307.0 | 310.9 |
| 51278 | TX 9 | 307.0 | 307.6 |
| 51278 | TX10 | 307.0 | 309.0 |
| 51278 | TX11 | 307.0 | 309.7 |
| 51278 | TX12 | 307.0 | 309.6 |
| 51278 | TX13 | 307.0 | 311.2 |
| 51278 | TX15 | 307.0 | 311.3 |
| 53078 | C3 | 302.8 | 302.0 |
| 53078 | C4 | 302.1 | 303.6 |
| 53078 | C5C6 | 304.5 | 306.6 |
| 53078 | F1 | 297.4 | 301.9 |
| 53078 | F2 | 297.6 | 302.5 |
| 53078 | RG83 | 302.4 | 300.3 |
| 53078 | RG88 | 304.7 | 300.3 |
| 53078 | R5 | 302.2 | 305.1 |
| 53078 | R6 | 301.7 | 305.5 |
| 53078 | R7 | 304.1 | 305.9 |
| 53078 | R8 | 302.6 | 305.1 |
| 53078 | TX 3 | 307.0 | 309.4 |
| 53078 | TX 4 | 304.0 | 314.0 |
| 53078 | TX 8 | 307.0 | 309.6 |
| 53078 | TX 9 | 304.0 | 314.6 |
| 53078 | TX10 | 300.0 | 309.5 |
| 53078 | TX11 | 300.0 | 310.4 |
| 53078 | TX12 | 304.0 | 314.9 |
| 53078 | TX13 | 300.0 | 314.9 |
| 53078 | TX15 | 300.0 | 314.0 |
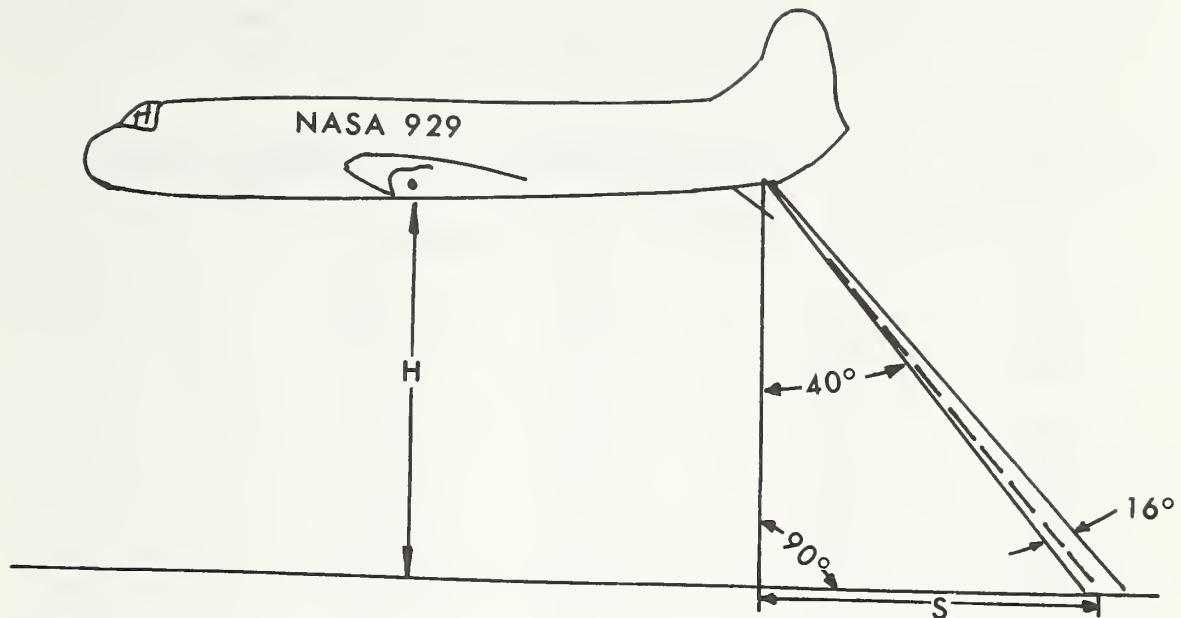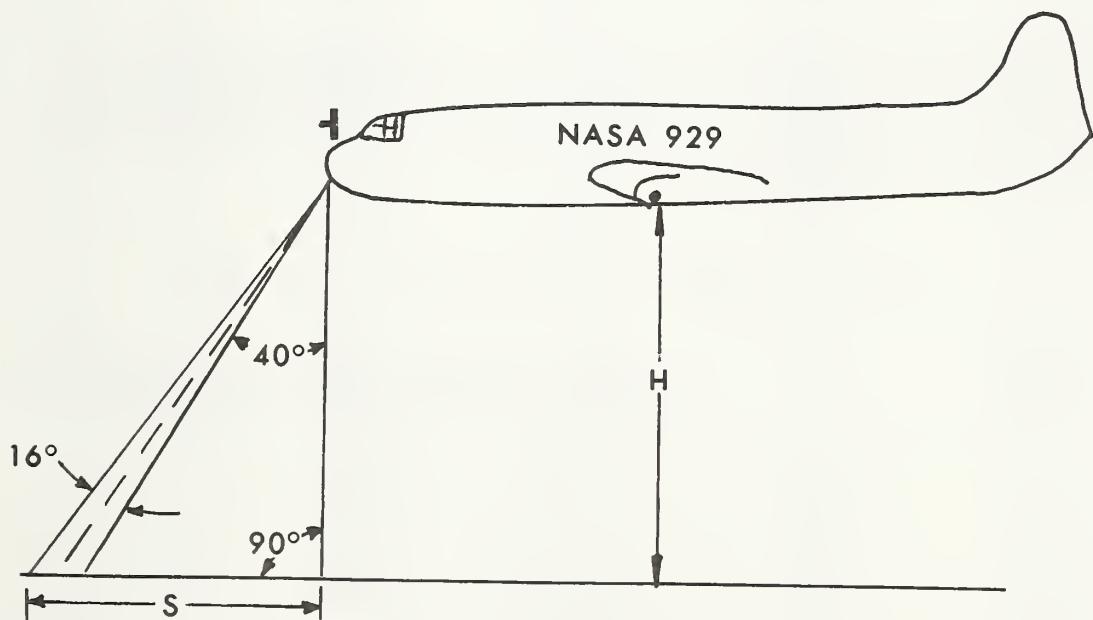
Figure 7.--Radiometer 40 degree look angle geometry: A, K band; B, C and L bands.

Table 18.--Time corrections for correlation of NERDAS and camera time data at 0-degree look angles

| Alti-tude | Time correction factors for ground speeds | | | | |
| | 224 kph | 245 kph | 261 kph | 280 kph | 299 kph |
| --- | --- | --- | --- | --- | --- |
| M | ----------------Sec/cm---------------- | | | | |
| 245 | 0.26 | 0.24 | 0.22 | 0.21 | 0.19 |
| 275 | .29 | .27 | .25 | .23 | .22 |
| 305 | .32 | .30 | .28 | .26 | .24 |
| 335 | .36 | .33 | .31 | .28 | .27 |
| 365 | .39 | .36 | .33 | .31 | .29 |

The time correction $\Delta T$ is computed by using S and the plane's ground speed as follows:

$$\Delta T = S(m) / (G(\frac{km}{hr}) * 1000(\frac{m}{km}) * \frac{1}{3600}(\frac{sec}{hr})) \qquad (2)$$

Typical values are listed in table 19. The correction is added to the NERDAS determined start and stop times. Average radiometer brightness temperatures and standard deviations for each site are obtained using a NASA program. Site average brightness temperatures for the K-band are listed in tables 20, 21, and 22.

Table 19.--Time corrections for 40° look angles

| Alti-tude | S | Time corrections for ground speeds | | | | |
| | | 205 kph | 224 kph | 243 kph | 280 kph | 299 kph |
| --- | --- | --- | --- | --- | --- | --- |
| M | M | ----------------Sec---------------- | | | | |
| 245 | 205 | 3.62 | 3.32 | 3.06 | 2.84 | 2.65 |
| 275 | 230 | 4.07 | 3.73 | 3.44 | 3.20 | 2.98 |
| 305 | 256 | 4.52 | 4.15 | 3.83 | 3.55 | 3.32 |
| 335 | 282 | 4.97 | 4.56 | 4.21 | 3.91 | 3.65 |
| 365 | 307 | 5.43 | 4.97 | 4.59 | 4.26 | 3.98 |

Table 20.--Ka band radiometer data

| | | BRIGHTNESS TEMPERATURES | | | |
|---|---|---|---|---|---|
| | | 0 DEG LOOK ANGLE | | 40 DEG LOOK ANGLE | |
| DATE | SITE | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION |
| | | | | DEG K | |
| 50178 | C3 | 275.2 | 274.4 | 275.6 | 279.7 |
| 50178 | C4 | 276.3 | 277.0 | - | - |
| 50178 | C5C6 | 288.2 | 286.9 | 290.4 | 291.3 |
| 50178 | F1 | 285.1 | 283.7 | 286.8 | 289.2 |
| 50178 | RG83 | 279.4 | 278.0 | 278.2 | 282.6 |
| 50178 | RG88 | 278.7 | 277.7 | - | - |
| 50178 | R5 | 289.9 | 289.4 | 291.4 | 291.9 |
| 50178 | R6 | 287.6 | 288.2 | 288.4 | 290.4 |
| 50178 | R7 | 280.3 | 278.2 | 283.6 | 287.3 |
| 50178 | R8 | 279.4 | 278.7 | 282.1 | 286.3 |
| 50178 | TX 3 | 301.9 | 301.6 | 296.6 | 299.1 |
| 50178 | TX 4 | 300.2 | 301.8 | 303.7 | 305.7 |
| 51278 | C3 | 285.8 | 295.6 | 284.7 | 290.9 |
| 51278 | C4 | 283.2 | 281.8 | - | - |
| 51278 | C5C6 | 289.5 | 288.8 | 292.8 | 293.7 |
| 51278 | F1 | 291.6 | 291.1 | 293.5 | 293.8 |
| 51278 | F2 | 294.0 | 292.5 | 294.8 | 295.5 |
| 51278 | RG83 | 286.8 | 287.0 | - | - |
| 51278 | RG88 | 290.6 | 290.4 | - | - |
| 51278 | R5 | 295.9 | 293.8 | 296.4 | 296.3 |
| 51278 | R6 | 292.7 | 292.3 | 294.8 | 295.1 |
| 51278 | R7 | 291.2 | 291.1 | - | - |
| 51278 | R8 | 290.8 | 292.1 | 292.0 | 294.9 |
| 51278 | TX 3 | 298.3 | 298.3 | 298.1 | 302.4 |
| 51278 | TX 4 | 303.9 | 302.7 | 304.8 | 305.2 |
| 51278 | TX 8 | 299.2 | 298.3 | 296.7 | 300.2 |
| 51278 | TX 9 | 299.4 | 299.2 | 300.0 | 301.1 |
| 51278 | TX10 | 296.3 | 295.7 | 300.7 | 300.2 |
| 51278 | TX11 | 297.8 | 295.8 | 300.6 | 301.8 |
| 51278 | TX12 | 304.6 | 303.3 | 307.0 | 307.2 |
| 51278 | TX13 | 303.0 | 302.2 | 302.7 | 305.1 |
| 51278 | TX15 | 304.0 | 303.5 | 304.8 | 306.3 |
| 53078 | C3 | - | - | - | - |
| 53078 | C4 | - | - | - | - |
| 53078 | C5C6 | 293.1 | 292.5 | 295.6 | 303.3 |
| 53078 | F1 | 297.0 | 295.9 | 297.6 | 297.3 |
| 53078 | F2 | 298.1 | 296.9 | 298.9 | 299.2 |
| 53078 | RG83 | 289.5 | 289.0 | - | - |
| 53078 | RG88 | 294.7 | 294.4 | - | - |
| 53078 | R5 | 298.1 | 298.0 | 300.3 | 301.5 |
| 53078 | R6 | 296.4 | 295.8 | 298.7 | 302.2 |
| 53078 | R7 | 293.2 | 293.0 | 297.9 | 301.3 |
| 53078 | R8 | 291.9 | 291.6 | 294.3 | 297.8 |
| 53078 | TX 3 | 299.1 | 298.7 | 297.1 | 300.0 |
| 53078 | TX 4 | 308.6 | 308.1 | 311.6 | 309.8 |
| 53078 | TX 8 | 297.6 | 296.7 | 292.7 | 294.6 |
| 53078 | TX 9 | 309.7 | 309.6 | 311.6 | 312.9 |
| 53078 | TX10 | 301.6 | 299.7 | 303.9 | 303.4 |
| 53078 | TX11 | 295.4 | 294.8 | 290.5 | 293.5 |
| 53078 | TX12 | 304.0 | 302.7 | 307.5 | 308.8 |
| 53078 | TX13 | 310.1 | 308.3 | 311.7 | 313.1 |
| 53078 | TX15 | 310.2 | 310.8 | 311.3 | 311.9 |

Table 21.--K band radiometer data

| | | BRIGHTNESS TEMPERATURES | | | |
| | | 0 DEG LOOK ANGLE | | 40 DEG LOOK ANGLE | |
| DATE | SITE | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION |
| | | ----------DEG K---------- | | | |
| 50178 | C3 | 272.6 | 274.2 | 273.0 | 280.0 |
| 50178 | C4 | 275.2 | 277.7 | - | - |
| 50178 | C5C6 | 287.2 | 288.7 | 288.4 | 292.2 |
| 50178 | F1 | 282.4 | 283.8 | 285.0 | 287.6 |
| 50178 | RG83 | 276.3 | 276.9 | 272.6 | 282.4 |
| 50178 | RG88 | 276.6 | 277.2 | - | - |
| 50178 | R5 | 286.6 | 288.3 | 286.6 | 292.0 |
| 50178 | R6 | 283.6 | 285.3 | 282.3 | 289.3 |
| 50178 | R7 | 274.6 | 276.2 | 278.7 | 286.9 |
| 50178 | R8 | 273.6 | 275.5 | 276.9 | 286.0 |
| 50178 | TX 3 | 299.9 | 300.9 | 296.1 | 298.0 |
| 50178 | TX 4 | 298.5 | 301.9 | 301.6 | 305.5 |
| 51278 | C3 | 284.7 | 285.5 | 283.4 | 291.1 |
| 51278 | C4 | 280.0 | 282.8 | - | - |
| 51278 | C5C6 | 288.5 | 290.2 | 290.6 | 295.0 |
| 51278 | F1 | 289.8 | 291.8 | 291.1 | 294.1 |
| 51278 | F2 | 291.5 | 293.0 | 293.7 | 296.1 |
| 51278 | RG83 | 287.8 | 289.2 | - | - |
| 51278 | RG88 | 289.6 | 290.2 | - | - |
| 51278 | R5 | 294.7 | 295.7 | 294.3 | 296.6 |
| 51278 | R6 | 292.0 | 293.9 | 292.1 | 295.4 |
| 51278 | R7 | 289.9 | 292.2 | - | - |
| 51278 | R8 | 290.5 | 292.4 | 290.3 | 295.5 |
| 51278 | TX 3 | 297.0 | 297.1 | 294.9 | 302.3 |
| 51278 | TX 4 | 300.6 | 301.9 | 301.9 | 305.1 |
| 51278 | TX 8 | 296.1 | 297.3 | 292.9 | 300.9 |
| 51278 | TX 9 | 297.2 | 299.6 | 296.9 | 301.5 |
| 51278 | TX10 | 295.6 | 297.6 | 298.1 | 301.3 |
| 51278 | TX11 | 296.7 | 298.2 | 297.8 | 304.5 |
| 51278 | TX12 | 301.7 | 303.8 | 304.7 | 307.0 |
| 51278 | TX13 | 300.3 | 302.5 | 299.3 | 305.6 |
| 51278 | TX15 | 300.9 | 303.0 | 301.1 | 306.2 |
| 53078 | C3 | - | - | - | - |
| 53078 | C4 | - | - | - | - |
| 53078 | C5C6 | 289.0 | 289.6 | 288.0 | 295.8 |
| 53078 | F1 | 291.7 | 292.9 | 293.0 | 294.7 |
| 53078 | F2 | 291.6 | 292.8 | 293.0 | 295.3 |
| 53078 | RG83 | 282.8 | 282.4 | - | - |
| 53078 | RG88 | 289.0 | 289.6 | - | - |
| 53078 | R5 | 290.9 | 292.8 | 293.3 | 296.8 |
| 53078 | R6 | 288.0 | 288.7 | 292.6 | 298.1 |
| 53078 | R7 | 286.2 | 287.6 | 289.8 | 296.9 |
| 53078 | R8 | 283.8 | 285.5 | 285.5 | 294.7 |
| 53078 | TX 3 | 295.3 | 296.5 | 293.5 | 299.6 |
| 53078 | TX 4 | 301.6 | 304.0 | 305.3 | 307.7 |
| 53078 | TX 8 | 294.2 | 295.4 | 290.1 | 295.1 |
| 53078 | TX 9 | 303.9 | 305.9 | 304.4 | 309.2 |
| 53078 | TX10 | 297.1 | 299.3 | 298.3 | 301.0 |
| 53078 | TX11 | 293.8 | 295.1 | 287.9 | 294.4 |
| 53078 | TX12 | 298.7 | 300.6 | 300.6 | 306.1 |
| 53078 | TX13 | 304.7 | 304.6 | 304.6 | 309.5 |
| 53078 | TX15 | 304.1 | 306.4 | 304.6 | 309.7 |

Table 22.--Ku band radiometer data

| | | BRIGHTNESS TEMPERATURES | | | |
|---|---|---|---|---|---|
| | | 0 DEG LOOK ANGLE | | 40 DEG LOOK ANGLE | |
| DATE | SITE | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION |
| | | -----DEG K----- | | | |
| 50178 | C3 | 261.5 | 262.3 | 263.2 | 272.0 |
| 50178 | C4 | 264.5 | 265.3 | - | - |
| 50178 | C5C6 | 279.2 | 280.0 | 282.6 | 286.7 |
| 50178 | F1 | 275.0 | 276.6 | 280.2 | 284.4 |
| 50178 | RG83 | 265.4 | 265.6 | 261.5 | 273.1 |
| 50178 | RG88 | 263.6 | 264.2 | - | - |
| 50178 | R5 | 276.6 | 277.6 | 280.4 | 285.8 |
| 50178 | R6 | 272.8 | 273.8 | 273.6 | 282.7 |
| 50178 | R7 | 262.3 | 263.4 | 267.5 | 279.1 |
| 50178 | R8 | 261.2 | 262.2 | 265.5 | 277.4 |
| 50178 | TX 3 | 291.7 | 293.8 | 289.8 | 293.3 |
| 50178 | TX 4 | 291.6 | 295.4 | 295.0 | 298.4 |
| 51278 | C3 | 275.0 | 275.5 | 275.9 | 285.3 |
| 51278 | C4 | 272.9 | 273.4 | - | - |
| 51278 | C5C6 | 281.4 | 282.0 | 286.3 | 289.8 |
| 51278 | F1 | 283.1 | 283.4 | 286.3 | 289.6 |
| 51278 | F2 | 284.8 | 284.6 | 289.0 | 291.1 |
| 51278 | RG83 | 277.6 | 278.3 | - | - |
| 51278 | RG88 | 279.7 | 281.1 | - | - |
| 51278 | R5 | 285.3 | 285.9 | 288.4 | 291.6 |
| 51278 | R6 | 282.8 | 282.3 | 287.9 | 290.8 |
| 51278 | R7 | 282.0 | 282.2 | - | - |
| 51278 | R8 | 282.4 | 283.1 | 284.1 | 290.7 |
| 51278 | TX 3 | 285.6 | 285.8 | 286.7 | 295.3 |
| 51278 | TX 4 | 290.5 | 291.8 | 294.4 | 299.1 |
| 51278 | TX 8 | 285.8 | 285.7 | 285.1 | 293.7 |
| 51278 | TX 9 | 288.5 | 289.6 | 290.7 | 296.3 |
| 51278 | TX10 | 287.8 | 288.4 | 293.1 | 296.3 |
| 51278 | TX11 | 287.5 | 288.9 | 291.0 | 297.6 |
| 51278 | TX12 | 294.8 | 294.5 | 299.5 | 301.9 |
| 51278 | TX13 | 292.1 | 292.5 | 292.9 | 298.3 |
| 51278 | TX15 | 293.2 | 292.9 | 295.0 | 300.6 |
| 53078 | C3 | - | - | - | - |
| 53078 | C4 | - | - | - | - |
| 53078 | C5C6 | - | - | - | - |
| 53078 | F1 | - | - | - | - |
| 53078 | F2 | - | - | - | - |
| 53078 | RG83 | - | - | - | - |
| 53078 | RG88 | - | - | - | - |
| 53078 | R5 | - | - | - | - |
| 53078 | R6 | - | - | - | - |
| 53078 | R7 | - | - | - | - |
| 53078 | R8 | - | - | - | - |
| 53078 | TX 3 | - | - | - | - |
| 53078 | TX 4 | - | - | - | - |
| 53078 | TX 8 | - | - | - | - |
| 53078 | TX 9 | - | - | - | - |
| 53078 | TX10 | - | - | - | - |
| 53078 | TX11 | - | - | - | - |
| 53078 | TX12 | - | - | - | - |
| 53078 | TX13 | - | - | - | - |
| 53078 | TX15 | - | - | - | - |

## C and L band radiometers

These systems were mounted in the nose of the aircraft. Each was used at 0° and 40° forward look angles. The system geometry at the 40° angle is shown in figure 7, B.

Data preparation procedures are similar to those described for the K band system. Equation 1 is used to determine S and equation 2 is used to estimate $\Delta T$ as was done for the 40° K band data. However, in this case, the time correction is subtracted from the NERDAS determined zero degrees start and stop times since the sensor covers the spot before the plane does.

Typical values for S and $\Delta T$ are listed in table 19 and data are prepared in the same manner as described for the K bands. C and L band site averages and variances are listed in tables 23 and 24.

## Passive microwave imaging system

As shown in figure 8, A, the passive microwave imaging system (PMIS) sensor points out of the back of the aircraft at an angle of approximately 49.2°. The sensor scans 33.2° on each side of the aircraft moving from left to right. Data are recorded for overlapping spots as (figure 8, B). To define the factors illustrated in figure 8, A and B, geometric relationships can be used. Table 25 also lists some typical values for these factors.

Time Correction.--The distance between the plane and the sensor beam position (S) can be used in conjunction with the ground speed of the aircraft (G) to compute the time which elapsed between the time the plane passed over a ground location and the time at which the scanner beam did ($\Delta T$). Equation 2 is used for this computation.

A photo center can be located on a PMIS printout by adding $\Delta T$ to the NERDAS time of the photo center. For example, suppose that photo frame 140 of the line described on the NERDAS list shown in table 15 was involved. From this printout the value of H is approximately 1,020 ft (311 m) and G is approximately 151 knots (280 kph) After conversion to metric and using the typical values illustrated in table 25, the value of $\Delta T$ is approximately 4.6 second. This is added to the photo center time of 18:54:15.5 to obtain the sensor coverage time of 18:54:20.1.

To locate an experimental site, the procedure for identifying the start and stop times followed for zero degrees is used. Then, the H and G values of the relevant photos are used to determine $\Delta T$ and to correct the start and stop times.

Table 23.--C band radiometer data

| | | BRIGHTNESS TEMPERATURES | | | |
|---|---|---|---|---|---|
| | | 0 DEG LOOK ANGLE | | 40 DEG LOOK ANGLE | |
| DATE | SITE | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION | HORIZONTAL POLARIZATION | VERTICAL POLARIZATION |
| | | | | -DEG K- | | |
| 50178 | C3 | 258.5 | 261.6 | 248.6 | 256.9 |
| 50178 | C4 | 264.0 | 264.9 | 253.5 | 261.5 |
| 50178 | C5C6 | 275.0 | 275.3 | 263.3 | 267.5 |
| 50178 | F1 | 278.4 | 282.0 | - | - |
| 50178 | RG83 | 256.9 | 259.1 | 228.3 | 246.5 |
| 50178 | RG88 | - | - | - | - |
| 50178 | R5 | 261.2 | 261.3 | 243.0 | 258.4 |
| 50178 | R6 | 250.8 | 252.2 | 236.3 | 253.8 |
| 50178 | R7 | 240.2 | 244.3 | 227.2 | 250.5 |
| 50178 | R8 | 240.4 | 244.8 | 228.5 | 248.6 |
| 50178 | TX 3 | - | - | 279.8 | 284.2 |
| 50178 | TX 4 | - | - | 283.0 | 283.8 |
| 51278 | C3 | 277.7 | 280.5 | 268.9 | 272.7 |
| 51278 | C4 | 276.1 | 273.7 | 263.4 | 271.6 |
| 51278 | C5C6 | 280.9 | 281.6 | 272.4 | 274.5 |
| 51278 | F1 | 281.7 | 285.3 | 271.3 | 275.8 |
| 51278 | F2 | 282.1 | 285.2 | 273.2 | 278.2 |
| 51278 | RG83 | 276.8 | 278.0 | - | - |
| 51278 | RG88 | 275.0 | 277.6 | - | - |
| 51278 | R5 | 281.7 | 284.4 | - | - |
| 51278 | R6 | 276.8 | 280.1 | 268.4 | 274.5 |
| 51278 | R7 | 279.1 | 282.7 | - | - |
| 51278 | R8 | 280.8 | 283.0 | 269.2 | 277.3 |
| 51278 | TX 3 | 293.5 | 291.4 | 278.5 | 285.1 |
| 51278 | TX 4 | 290.9 | 294.7 | 281.4 | 285.3 |
| 51278 | TX 8 | 291.2 | 294.0 | 276.9 | 281.2 |
| 51278 | TX 9 | 282.3 | 286.1 | 270.6 | 279.5 |
| 51278 | TX10 | 284.9 | 287.6 | 278.5 | 280.1 |
| 51278 | TX11 | 293.1 | 297.5 | 285.8 | 287.2 |
| 51278 | TX12 | 292.0 | 295.1 | 280.1 | 285.5 |
| 51278 | TX13 | 290.8 | 297.4 | 283.6 | 286.9 |
| 51278 | TX15 | 291.2 | 294.3 | 278.8 | 285.8 |
| 53078 | C3 | - | - | - | - |
| 53078 | C4 | - | - | - | - |
| 53078 | C5C6 | 254.8 | 250.9 | 240.9 | 260.1 |
| 53078 | F1 | 275.1 | 279.3 | 268.1 | 275.4 |
| 53078 | F2 | 276.5 | 278.6 | 268.6 | 275.7 |
| 53078 | RG83 | - | - | - | - |
| 53078 | RG88 | - | - | - | - |
| 53078 | R5 | 258.5 | 261.9 | 246.8 | 265.4 |
| 53078 | R6 | 249.1 | 252.5 | 238.3 | 259.8 |
| 53078 | R7 | 257.4 | 262.7 | 238.9 | 262.9 |
| 53078 | R8 | 251.5 | 255.3 | 239.9 | 259.2 |
| 53078 | TX 3 | 294.3 | 297.1 | 281.8 | 285.8 |
| 53078 | TX 4 | 298.3 | 302.3 | 288.0 | 290.4 |
| 53078 | TX 8 | 292.3 | 294.8 | 283.4 | 284.9 |
| 53078 | TX 9 | 299.0 | 301.7 | 287.2 | 290.4 |
| 53078 | TX10 | 295.2 | 297.6 | 284.8 | 281.9 |
| 53078 | TX11 | 293.9 | 296.4 | 282.3 | 283.2 |
| 53078 | TX12 | 294.6 | 298.2 | 282.2 | 285.8 |
| 53078 | TX13 | 296.4 | 298.4 | 282.5 | 289.1 |
| 53078 | TX15 | 297.4 | 301.0 | 283.1 | 288.6 |

Table 24.--L band radiometer data, horizontal polarization

| | | BRIGHTNESS TEMPERATURES | |
| DATE | SITE | 0 DEG LOOK ANGLE | 40 DEG LOOK ANGLE |
| | | --------DEG K-------- | |
| 50178 | C3 | 250.9 | 224.3 |
| 50178 | C4 | 250.3 | 221.3 |
| 50178 | C5C6 | 250.0 | 221.4 |
| 50178 | F1 | 252.1 | 227.7 |
| 50178 | RG83 | 226.6 | 201.8 |
| 50178 | RG88 | 229.9 | - |
| 50178 | R5 | 234.9 | 201.4 |
| 50178 | R6 | 226.3 | 192.4 |
| 50178 | R7 | 226.8 | 198.9 |
| 50178 | R8 | 237.0 | - |
| 50178 | TX 3 | 279.7 | 250.0 |
| 50178 | TX 4 | - | - |
| 51278 | C3 | 271.5 | 243.6 |
| 51278 | C4 | 271.9 | 235.4 |
| 51278 | C5C6 | 262.2 | 230.5 |
| 51278 | F1 | 250.7 | 214.8 |
| 51278 | F2 | 250.6 | 221.4 |
| 51278 | RG83 | 256.4 | - |
| 51278 | RG88 | 248.7 | - |
| 51278 | R5 | 248.5 | 212.2 |
| 51278 | R6 | 245.6 | 210.6 |
| 51278 | R7 | 257.4 | - |
| 51278 | R8 | - | 227.8 |
| 51278 | TX 3 | 277.0 | 241.9 |
| 51278 | TX 4 | 265.5 | 226.0 |
| 51278 | TX 8 | 256.6 | 220.3 |
| 51278 | TX 9 | 245.0 | 208.6 |
| 51278 | TX10 | 259.8 | 236.2 |
| 51278 | TX11 | 264.8 | 233.8 |
| 51278 | TX12 | 255.8 | 220.8 |
| 51278 | TX13 | 257.3 | 228.1 |
| 51278 | TX15 | 260.8 | 227.0 |
| 53078 | C3 | - | - |
| 53078 | C4 | - | - |
| 53078 | C5C6 | 229.2 | 189.7 |
| 53078 | F1 | 231.0 | 202.2 |
| 53078 | F2 | 235.2 | 208.6 |
| 53078 | RG83 | 236.4 | - |
| 53078 | RG88 | 223.3 | - |
| 53078 | R5 | 222.1 | 192.0 |
| 53078 | R6 | 224.1 | - |
| 53078 | R7 | 226.0 | 198.2 |
| 53078 | R8 | 233.5 | 205.4 |
| 53078 | TX 3 | 289.5 | 258.4 |
| 53078 | TX 4 | 283.3 | 252.6 |
| 53078 | TX 8 | 292.1 | 265.1 |
| 53078 | TX 9 | 288.0 | 255.2 |
| 53078 | TX10 | 285.5 | 263.3 |
| 53078 | TX11 | 294.4 | 265.6 |
| 53078 | TX12 | 277.7 | 248.4 |
| 53078 | TX13 | 278.0 | 247.7 |
| 53078 | TX15 | 279.1 | 240.8 |
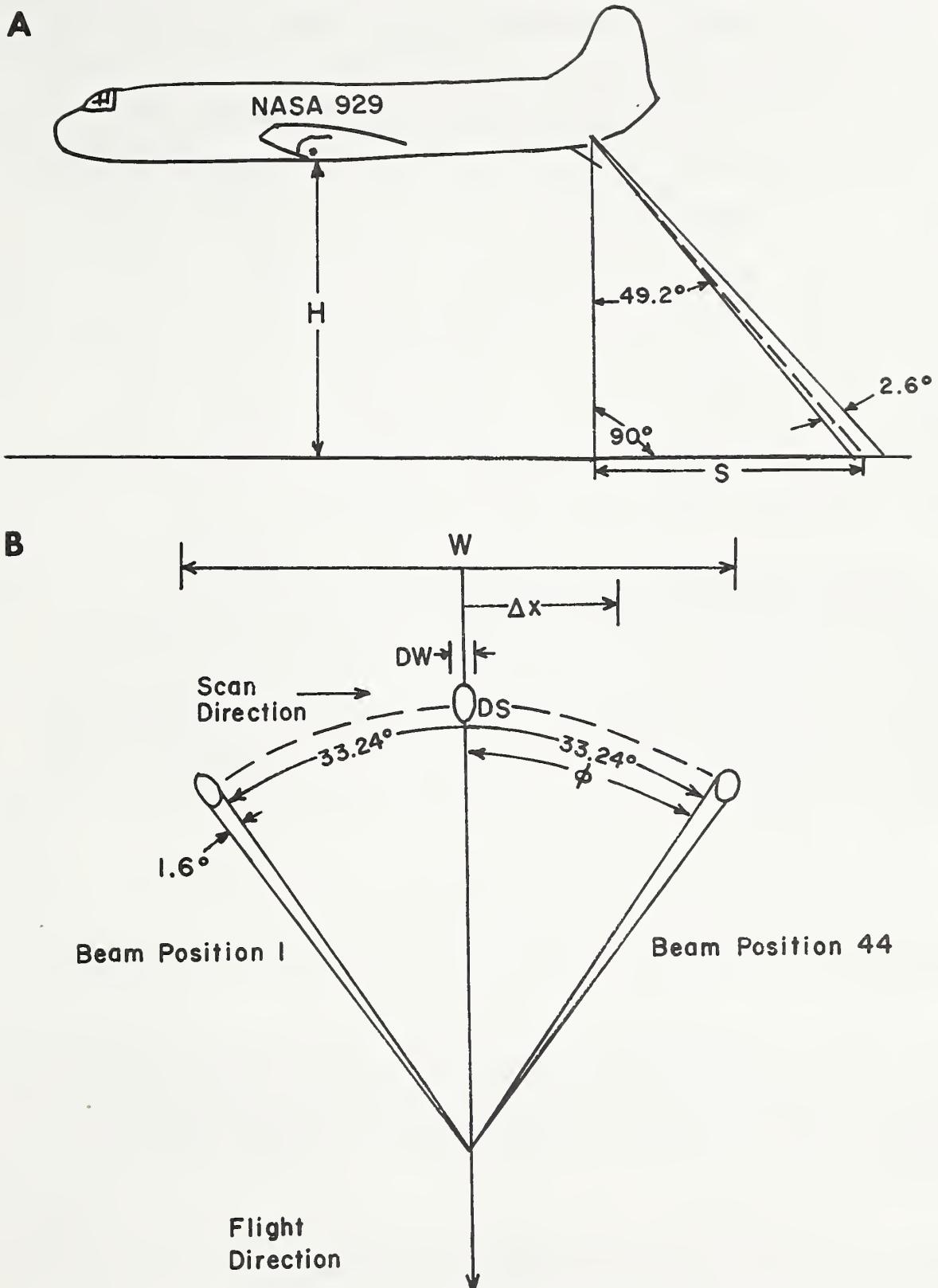
Figure 8.--PMIS radiometer: <u>A</u>, Look angle geometry; <u>B</u>, scanner geometry.

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Table 25.--Geometric relationships and time corrections for PMIS data

| Alti-tude | Geometric relationship[1/] | | | | Time corrections for ground speeds | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | S | W | DS | DW | 224 kph | 243 kph | 261 kph | 280 kph | 299 kph |
| | ----------M---------------- | | | | -------------Seconds--------------- | | | | |
| 245 | 283 | 322 | 27 | 16 | 4.58 | 4.23 | 3.93 | 3.67 | 3.44 |
| 275 | 318 | 362 | 31 | 19 | 5.16 | 4.76 | 4.42 | 4.13 | 3.87 |
| 305 | 354 | 402 | 34 | 21 | 5.73 | 5.29 | 4.91 | 4.58 | 4.30 |
| 335 | 389 | 443 | 37 | 23 | 6.30 | 5.82 | 5.40 | 5.04 | 4.73 |
| 365 | 425 | 513 | 41 | 25 | 6.88 | 6.35 | 5.89 | 5.50 | 5.16 |

[1/]S = 1.116 H, W = 1.319 H, DS = 0.111 H, DW = 0.068 H.


Geometric correction.--PMIS data can be used to generate an alphanumeric character map by assigning different characters to brightness temperature intervals. However, in order to use the data for locating fields or watersheds certain geometric distortions must be corrected. In the direction perpendicular to the flightline, one distortion is caused by the data recorded on a conical beam (fig. 9), as a line consisting of 44 elements that overlap. The true ground locations of a stationary aircraft scan are illustrated in figure 9 as the solid line. To determine how far any conical beam position center is displaced from the chord, the following equation is used:

$$DYS = S*\cos (33.24 - 1.51*BP) - S*\cos \Phi \qquad (3)$$

$$= 1.16*H \cos (33.24 - 1.51*BP) - 0.97*H$$

where BP is the beam position number and V is the ground speed in metrics per second.

A second correction must be applied since a scan takes 1 second during which time the aircraft is in motion. After 1 second the plane would be in a new beam position 44 with an equivalent swath shown as the dashed line in figure 9. This correction is computed straight from ground speed and beam position time. By using the following equation, the displacement is computed:

$$DYP = V* BP/44 \qquad (4)$$

The net displacement along the flightline at a beam position J on scan line I is computed as follows:

$$Y (I,J) = Y (I,1) - DYS (I,J) + DYP (I,J) \qquad (5)$$
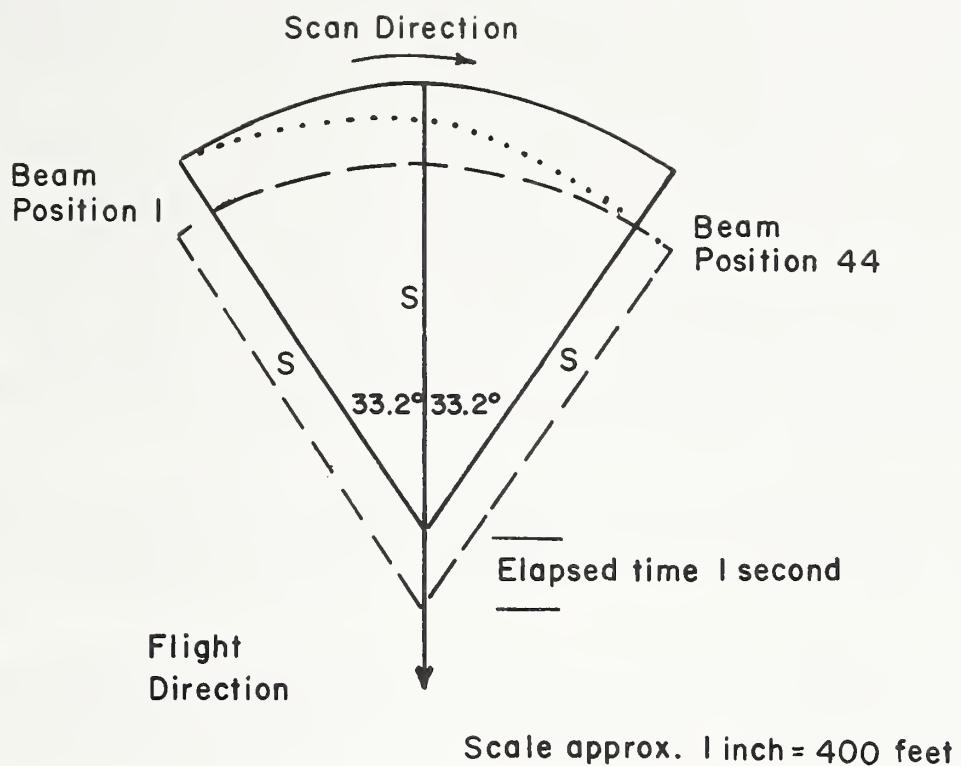
Figure 9.--PMIS radiometer beam position locations.

As an example, for beam position J = 44 at an altitude of H = 305 m  and G = 224 kph.

$$Y (I,44) = Y (I,1) - 0 + 61 = Y (I,1) = 61 \qquad (6)$$

Adjustment for the overlap of beam positions across each scan line is also necessary to produce a useful character map.  One adjustment is the determining of the center location of each beam position and using this for mapping.  This can be done by dividing the swath width by the number of beam positions to determine the distance between centers, DX.  One half of the beam positions fall on each side of the flightline.  The procedure described above can be applied to each data point to determine its approximate X and Y coordinates.  At each point one would have brightness temperature (BT(I,J), and location Y(I,J) and X (I,J)).

The data in this corrected form can be used to compute the average PMIS response for a field by determining the stop and start times as well as the left and right extreme points and averaging the values within the boundaries.  However, in order to locate the boundaries a character map is required.

Contour mapping.--A printout can be generated from this raw-data set by using an intermediate contour mapping program.  In these programs, a square grid point system of specified density is generated by resampling the original data.

These data can be printed by assigning characters to each grid point or a larger overlay grid can be used and all points within it averaged.  This latter procedure is useful for scaling.

A program was written in FORTRAN to perform the geometric corrections on the raw PMIS data and to produce a new square grid of resampled data, which can be outputed as a contour map of brightness temperatures.

The geometric corrections previously described include one for the arc of the swath and two for plane movement which are based upon beam positon, altitude, and ground speed.

The PMIS data are input as an I, J matrix where I is the scan line and J is the beam position.  For each scanline the time is also input to identify the average altitude and ground speed.  Ground speed and altitude are determined from the NERDAS printout.

Following the procedure previously described for computing $\Delta T$, the photocenter times are corrected and the time, altitude, and ground speed for each are recorded as a matrix for input.  This set of photo centers should cover the time period for the entire PMIS data set to be corrected.

Each PMIS scan line is assigned an altitude and ground speed by a linear interpolation between the values recorded at its two surrounding photo centers and the elapsed time since the first. PMIS observation time is TPM (I) and the surrounding photo center pair times are TPH (K) and TPH (K + 1). Altitude pairs are ALT (K) and ALT (K + 1) and ground speed pairs are GDS (K) and GDS (K + 1). The calculations for scanline altitude and ground speed are:

$$H = ALT(K)+(ALT(K+1)-ALT(K))*(TPM(I)-TPH(K))/(TPH(K+1)-TPH(K)) \qquad (7)$$
and
$$G = GDS(K)+(GDS(K+1)-GDS(K))*(TPM(I)-TPH(K))/(TPH(K+1)-TPH(K)) \qquad (8)$$

These values are used in conjunction with equations 4, 5, and 6 to compute the location of each scan line beam position related to a 0, 0 point.

Following the geometric correction, the new grid is generated and used to produce a contour map. Values from the new grid can be stored for field averaging once the boundaries are identified. The program is set up to process time sequential PMIS data sets. An example of the output is shown in figure 10.

Site averaging.--The geometric correction and contour mapping program create a data file for each segment of the brightness temperatures and their locations corresponding to the contour maps. Site boundaries are then defined from the printouts and input to an averaging program which computes the mean and standard deviation for each site. Results obtained for each site are listed in table 26.

## Scatterometers

The output of the scatterometer is recorded by a Mincom wideband recorder that has a bandwidth coverage from DC to 20 KHz. Data are recorded on a magnetic tape with 14 data channels and with a carrier modulating frequency of 108 KHz. The time of data taking is recorded through standard time code and NERDAS on two separated channels. In addition to the time information, NERDAS also records the aircraft navigation parameters, such as altitude, air speed, ground speed, roll pitch, and drift angles.

Due to the high cost of data processing only selected time frames were processed. Backscattering coefficients for the test sites are presented in table 27, 28 and 29 for the C, L, and P bands, respectively. Valves are tabulated for all available look angles.

Several system problems were encountered during the mission which greatly reduced the usable data from the scatterometers.

PMIS BRIGHTNESS TEMPERATURE MAP

CHICKASHA, OK DAY 150 LINE 1 RUN 3

```
56    /////      .#####..##*##.#####
57    ///    / / /.##########*##*./.####
58    /////////....#########**##*/ /#***
59    ///////....###########***#../ /#***
60    ///////....###########***#../ /#***
61    ////......###.#*.###*###./ /#***
62    ///....#*..####/.########*. /#***
63    ///....#....#./.########*....###
64    ///////..//././/-.###.///##..##.
65    //// //..#/ /. /.###.  /.....
66    ///////..// ////.##// //..
67    ///////.// ///..#.    /  .###
68    ./////////////.###/   /.//.###
69    ...////////////.##/  .##..####
70    ///////////////..#/  /..######
71    // ////////////.#../ ///.#####
72    /    /   ///..///  /.####
73          ///////.////.####
74          /// /.......###.
75        /   //#########.
76          ...####.
77          ///.....
78        // ///.
79             / /
80             /
81          /  /
82           /
83
84
85
86
87                     //
88              /  ./  ///
89              /..// //
90             /////// //
91    //////////        /
92        /
93    //
94    //
95    //
96    //         /
97    /.///      //..//// /
98    //        //...........////
99    /       /.//.###.......
100          ///..####.#....
101    /   //..###.####.##..*
102    /......###*##*##*##*##*.#
103    #####*###*###**#######*#####
104    #####*###*###**##*######*####
105    **#####*##*###*##*##****#####
106    **######*#*###*###**##*##*####
107    **######*#*###*##*##*##*##*###
108    ***##*#*##*#*##*##*##*##*####
109    ***##*#*##*#*##*##*##*##*####
110    ***#*#*#############*#####
111    ###*#*##*##*##*#######*####
112    ########*...########***#***
113    ###.#*...../..#######*#####
114    ###..../// //.############
115    **......//////..##########
116    .../....////////..#########
117    ../////.////////.####.####
118    .// ///////////.####.#####
119    //       ////// /..##...#.##
120    //       ////  /.##.....###
```

| Brightness temperature interval | Symbol |
|---|---|
| -deg K- | |
| 200 – 220 | |
| 220 – 240 | / |
| 240 – 260 | . |
| 260 – 280 | * |
| 280 – 300 | # |

Figure 10.--Example of PMIS radiometer alphanumeric map, Chickasha, Okla., flightline 1, May 30, 1978.

Table 26.--PMIS radiometer site averaged data

| | | PMIS BRIGHTNESS TEMPERATURE | | | |
| | | HORIZONTAL POLARIZATION | | VERTICAL POLARIZATION | |
| DATE | SITE | MEAN | STANDARD DEVIATION | MEAN | STANDARD DEVIATION |
| | | | | DEG K | |
| 50178 | C3 | 262.0 | 6.0 | 270.2 | 5.6 |
| 50178 | C4 | 265.5 | 6.6 | 274.9 | 10.9 |
| 50178 | C5C6 | 287.6 | 3.1 | 284.1 | 6.6 |
| 50178 | F1 | 285.1 | 2.4 | 284.2 | 3.0 |
| 50178 | RG83 | - | - | 286.3 | 2.6 |
| 50178 | RG88 | - | - | - | - |
| 50178 | R5 | 276.4 | 7.0 | 277.2 | 5.6 |
| 50178 | R6 | 267.3 | 5.4 | 281.1 | 5.4 |
| 50178 | R7 | 254.0 | 6.3 | 275.1 | 4.7 |
| 50178 | R8 | 260.5 | 8.4 | 277.2 | 4.0 |
| 50178 | TX 3 | - | - | - | - |
| 50178 | TX 4 | - | - | - | - |
| 51278 | C3 | 273.9 | 5.6 | 284.5 | 3.1 |
| 51278 | C4 | 268.3 | 5.3 | 285.2 | 7.8 |
| 51278 | C5C6 | 286.6 | 3.4 | 288.9 | 3.6 |
| 51278 | F1 | 288.3 | 3.0 | 288.1 | 3.2 |
| 51278 | F2 | 289.3 | 2.2 | 289.1 | 2.5 |
| 51278 | RG83 | - | - | - | - |
| 51278 | RG88 | - | - | - | - |
| 51278 | R5 | 289.7 | 2.6 | 289.5 | 2.7 |
| 51278 | R6 | 288.1 | 2.2 | 289.5 | 2.6 |
| 51278 | R7 | - | - | - | - |
| 51278 | R8 | - | - | - | - |
| 51278 | TX 3 | - | - | - | - |
| 51278 | TX 4 | - | - | - | - |
| 51278 | TX 8 | - | - | - | - |
| 51278 | TX 9 | - | - | - | - |
| 51278 | TX10 | - | - | - | - |
| 51278 | TX11 | - | - | - | - |
| 51278 | TX12 | - | - | - | - |
| 51278 | TX13 | - | - | - | - |
| 51278 | TX15 | - | - | - | - |
| 53078 | C3 | 205.5 | 21.4 | 256.2 | 14.9 |
| 53078 | C4 | 205.9 | 20.1 | 243.9 | 16.1 |
| 53078 | C5C6 | 272.6 | 15.6 | 279.3 | 21.0 |
| 53078 | F1 | - | - | - | - |
| 53078 | F2 | - | - | - | - |
| 53078 | RG83 | - | - | - | - |
| 53078 | RG88 | - | - | - | - |
| 53078 | R5 | 270.9 | 5.9 | - | - |
| 53078 | R6 | 271.0 | 5.2 | - | - |
| 53078 | R7 | 264.4 | 7.3 | 282.3 | 4.9 |
| 53078 | R8 | 266.6 | 7.7 | 285.4 | 3.7 |
| 53078 | TX 3 | - | - | - | - |
| 53078 | TX 4 | - | - | - | - |
| 53078 | TX 8 | - | - | - | - |
| 53078 | TX 9 | - | - | - | - |
| 53078 | TX10 | - | - | - | - |
| 53078 | TX11 | - | - | - | - |
| 53078 | TX12 | - | - | - | - |
| 53078 | TX13 | - | - | - | - |
| 53078 | TX15 | - | - | - | - |

Table 27.--C band scatterometer data

| | | BACKSCATTERING COEFFICIENT | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DEGREE OF LOOK ANGLE | | | | | | | | | |
| DATE | SITE | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| | | | | | | | DB | | | | | |
| 50178 | C3 | - | - | - | - | - | - | - | - | - | - |
| 50178 | C4 | - | - | - | - | - | - | - | - | - | - |
| 50178 | C5C6 | - | - | - | - | - | - | - | - | - | - |
| 50178 | F1 | - | - | - | - | - | - | - | - | - | - |
| 50178 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 50178 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 50178 | R5 | - | - | - | - | - | - | - | - | - | - |
| 50178 | R6 | - | - | - | - | - | - | - | - | - | - |
| 50178 | R7 | - | - | - | - | - | - | - | - | - | - |
| 50178 | R8 | - | - | - | - | - | - | - | - | - | - |
| 50178 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 50178 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 51278 | C3 | 0.7 | -6.2 | -8.3 | -10.7 | -12.1 | -14.1 | -14.7 | -16.3 | -17.9 | -19.5 |
| 51278 | C4 | 4.1 | -5.5 | -8.3 | -9.8 | -11.4 | -12.1 | -14.5 | -16.1 | -17.9 | -19.1 |
| 51278 | C5C6 | 3.0 | -7.9 | -10.3 | -11.3 | -12.2 | -13.3 | -13.8 | -13.9 | -15.6 | -16.1 |
| 51278 | F1 | 0.1 | -6.4 | -10.2 | -13.0 | -14.0 | -15.4 | -16.6 | -18.1 | -19.0 | -20.1 |
| 51278 | F2 | -1.4 | -8.6 | -11.4 | -12.7 | -14.8 | -16.5 | -17.1 | -17.7 | -19.4 | -19.8 |
| 51278 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 51278 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 51278 | R5 | 0.9 | -8.8 | -13.4 | -15.3 | -16.3 | -17.6 | -17.4 | -18.8 | -19.0 | -20.6 |
| 51278 | R6 | 1.3 | -6.4 | -11.5 | -14.0 | -15.7 | -17.9 | -17.8 | -18.8 | -19.0 | -20.2 |
| 51278 | R7 | 2.0 | -7.3 | -9.9 | -11.3 | -13.6 | -15.7 | -16.6 | -18.5 | -19.1 | -21.7 |
| 51278 | R8 | -0.1 | -7.7 | -11.1 | -13.2 | -14.7 | -15.7 | -15.5 | -15.8 | -18.1 | -19.0 |
| 51278 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 8 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 9 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX10 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX11 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX12 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX13 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX15 | - | - | - | - | - | - | - | - | - | - |
| 53078 | C3 | 5.6 | -5.8 | -10.2 | -14.3 | -16.2 | -19.0 | -21.0 | -22.5 | -23.8 | -26.0 |
| 53078 | C4 | 5.6 | -4.3 | -8.8 | -12.5 | -15.3 | -17.3 | -19.5 | -20.9 | -23.2 | -23.6 |
| 53078 | C5C6 | 6.7 | 0.4 | -2.9 | -5.4 | -7.1 | -8.7 | -10.7 | -11.7 | -11.7 | -14.1 |
| 53078 | F1 | 3.8 | -2.7 | -5.6 | -8.1 | -9.7 | -12.1 | -12.3 | -13.9 | -16.1 | -17.6 |
| 53078 | F2 | 4.8 | -1.8 | -5.0 | -8.0 | -10.1 | -12.5 | -14.2 | -15.1 | -17.2 | -18.7 |
| 53078 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 53078 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 53078 | R5 | 9.9 | -0.5 | -6.2 | -9.5 | -11.8 | -13.8 | -15.4 | -15.5 | -18.1 | -18.8 |
| 53078 | R6 | 8.0 | -0.6 | -5.5 | -8.6 | -10.9 | -12.2 | -14.1 | -15.5 | -17.5 | -17.9 |
| 53078 | R7 | 12.7 | 3.2 | -2.7 | -6.0 | -8.8 | -12.0 | -13.9 | -14.4 | -15.5 | -16.3 |
| 53078 | R8 | 9.1 | 1.8 | -3.7 | -6.6 | -8.8 | -11.1 | -12.2 | -14.3 | -15.0 | -17.1 |
| 53078 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 8 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 9 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX10 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX11 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX12 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX13 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX15 | - | - | - | - | - | - | - | - | - | - |

Table 28.--L band scatterometer data

| | | BACKSCATTERING COEFFICIENT | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DEGREE OF LOOK ANGLE | | | | | | | | | |
| DATE | SITE | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| | | DB | | | | | | | | | |
| 50178 | C3 | -5.4 | -7.9 | -8.5 | -10.4 | -13.6 | -14.4 | -15.7 | -18.3 | -20.3 | -21.5 |
| 50178 | C4 | -2.9 | -8.3 | -6.8 | -10.3 | -11.6 | -14.3 | -14.2 | -14.7 | -17.2 | -21.1 |
| 50178 | C5C6 | -7.4 | -10.9 | -13.3 | -14.4 | -14.2 | -17.2 | -18.7 | -20.5 | -21.3 | -23.9 |
| 50178 | F1 | -0.4 | -4.8 | -7.5 | -10.6 | -14.9 | -17.2 | -18.8 | -19.8 | -22.3 | -23.4 |
| 50178 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 50178 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 50178 | R5 | -1.2 | -8.9 | -13.2 | -16.2 | -18.5 | -19.7 | -20.7 | -22.5 | -24.4 | -26.8 |
| 50178 | R6 | 22.6 | -5.2 | -11.2 | -15.2 | -17.7 | -19.4 | -20.5 | -22.5 | -22.1 | -23.5 |
| 50178 | R7 | 67.8 | -2.4 | -7.0 | -10.8 | -14.0 | -15.7 | -17.9 | -19.7 | -22.9 | -22.9 |
| 50178 | R8 | 2.5 | -5.1 | -7.1 | -10.5 | -12.8 | -14.0 | -16.1 | -15.3 | -17.9 | -20.1 |
| 50178 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 50178 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 51278 | C3 | -0.4 | -3.0 | -6.4 | -10.7 | -13.9 | -16.6 | -17.9 | -20.8 | -20.5 | -23.4 |
| 51278 | C4 | 0.3 | -5.1 | -9.4 | -11.7 | -14.5 | -17.2 | -18.4 | -22.2 | -21.6 | -22.7 |
| 51278 | C5C6 | -2.4 | -8.1 | -11.0 | -14.1 | -16.7 | -19.8 | -21.1 | -24.0 | -24.6 | -24.9 |
| 51278 | F1 | -1.6 | -6.4 | -9.9 | -12.3 | -15.1 | -18.6 | -19.6 | -21.1 | -23.1 | -23.7 |
| 51278 | F2 | -0.9 | -7.6 | -7.9 | -12.5 | -16.4 | -18.5 | -21.0 | -23.1 | -24.8 | -25.0 |
| 51278 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 51278 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 51278 | R5 | 2.5 | -4.3 | -12.7 | -16.0 | -18.9 | -21.2 | -22.5 | -25.4 | -26.3 | -26.9 |
| 51278 | R6 | 4.0 | -1.9 | -7.7 | -12.7 | -17.7 | -20.2 | -22.7 | -25.4 | -26.2 | -27.9 |
| 51278 | R7 | -3.6 | -9.7 | -11.6 | -14.7 | -17.7 | -17.6 | -21.1 | -23.6 | -24.7 | -23.1 |
| 51278 | R8 | -3.4 | -8.4 | -11.6 | -14.3 | -17.3 | -18.3 | -19.4 | -20.4 | -21.7 | -21.0 |
| 51278 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 8 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 9 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX10 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX11 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX12 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX13 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX15 | - | - | - | - | - | - | - | - | - | - |
| 53078 | C3 | -6.0 | -13.8 | -16.3 | -19.8 | -22.8 | -24.7 | -26.5 | -28.0 | -28.6 | -28.9 |
| 53078 | C4 | -3.2 | -10.5 | -14.1 | -18.3 | -21.9 | -22.0 | -25.8 | -28.5 | -29.2 | -30.5 |
| 53078 | C5C6 | -4.2 | -11.1 | -13.6 | -15.5 | -16.3 | -17.8 | -21.0 | -22.7 | -24.4 | -26.0 |
| 53078 | F1 | 3.1 | -0.6 | -4.0 | -6.2 | -10.1 | -12.7 | -16.9 | -17.5 | -19.5 | -22.5 |
| 53078 | F2 | 2.4 | -1.3 | -5.5 | -7.4 | -10.8 | -13.2 | -17.5 | -20.1 | -21.5 | -23.5 |
| 53078 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 53078 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 53078 | R5 | 4.0 | -4.7 | -9.7 | -15.3 | -17.8 | -20.2 | -22.0 | -24.3 | -25.4 | -25.8 |
| 53078 | R6 | 3.7 | -6.0 | -11.2 | -14.7 | -17.8 | -19.1 | -21.6 | -22.4 | -23.9 | -23.8 |
| 53078 | R7 | 32.4 | -0.8 | -6.8 | -11.1 | -13.2 | -16.2 | -17.8 | -18.8 | -20.8 | -21.1 |
| 53078 | R8 | 6.5 | -1.4 | -6.0 | -10.4 | -13.2 | -15.3 | -16.4 | -17.6 | -18.7 | -19.2 |
| 53078 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 8 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 9 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX10 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX11 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX12 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX13 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX15 | - | - | - | - | - | - | - | - | - | - |

Table 29.--P band scatterometer data

| | | BACKSCATTERING COEFFICIENT | | | | | | | | |
| | | DEGREE OF LOOK ANGLE | | | | | | | | |
| DATE | SITE | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | | | | | | | —DB— | | | | |
| 50178 | C3 | -27.2 | -35.7 | -42.1 | -42.0 | -44.6 | -43.1 | -46.7 | -43.5 | -45.2 | -42.8 |
| 50178 | C4 | -24.7 | -32.0 | -38.1 | -39.2 | -40.5 | -39.7 | -43.9 | -38.7 | -37.1 | -45.0 |
| 50178 | C5C6 | -16.8 | -35.1 | -40.4 | -42.0 | -45.7 | -40.6 | -44.6 | -44.1 | -42.4 | -42.0 |
| 50178 | F1 | -11.0 | -30.7 | -34.7 | -40.6 | -42.2 | -43.5 | -44.3 | -42.1 | -40.6 | -38.8 |
| 50178 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 50178 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 50178 | R5 | -31.3 | -42.9 | -47.4 | -46.9 | -49.8 | -48.8 | -47.0 | -43.4 | -44.5 | -37.8 |
| 50178 | R6 | -26.3 | -35.6 | -45.8 | -48.6 | -51.4 | -50.6 | -47.8 | -51.8 | -44.0 | -44.2 |
| 50178 | R7 | -23.6 | -31.7 | -43.9 | -45.3 | -45.0 | -43.1 | -43.7 | -40.9 | -41.6 | -39.5 |
| 50178 | R8 | -25.5 | -33.9 | -36.4 | -34.7 | -33.7 | -33.3 | -34.5 | -35.6 | -32.9 | -32.5 |
| 50178 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 50178 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 51278 | C3 | -23.2 | -33.0 | -43.9 | -45.3 | -43.9 | -41.9 | -42.5 | -41.1 | -41.1 | -39.1 |
| 51278 | C4 | -24.5 | -34.7 | -44.1 | -47.2 | -48.1 | -43.3 | -46.2 | -42.7 | -41.3 | -37.7 |
| 51278 | C5C6 | -22.9 | -38.6 | -46.6 | -49.2 | -48.2 | -49.4 | -50.9 | -50.8 | -50.5 | -47.8 |
| 51278 | F1 | -30.3 | -42.5 | -42.2 | -47.3 | -47.6 | -48.8 | -50.7 | -47.8 | -47.5 | -48.1 |
| 51278 | F2 | -22.3 | -37.6 | -46.7 | -47.1 | -46.0 | -46.9 | -46.5 | -43.2 | -39.1 | -37.4 |
| 51278 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 51278 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 51278 | R5 | -20.8 | -34.4 | -41.5 | -45.1 | -46.4 | -45.8 | -47.7 | -47.1 | -44.1 | -45.6 |
| 51278 | R6 | -26.6 | -37.7 | -49.8 | -47.5 | -50.7 | -49.0 | -51.3 | -50.1 | -49.8 | -46.2 |
| 51278 | R7 | - | - | - | - | - | - | - | - | - | - |
| 51278 | R8 | -21.6 | -30.5 | -34.6 | -35.1 | -35.9 | -35.9 | -35.7 | -34.2 | -33.2 | -34.3 |
| 51278 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 8 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX 9 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX10 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX11 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX12 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX13 | - | - | - | - | - | - | - | - | - | - |
| 51278 | TX15 | - | - | - | - | - | - | - | - | - | - |
| 53078 | C3 | -24.8 | -31.7 | -37.7 | -38.4 | -39.2 | -39.6 | -39.4 | -37.8 | -38.5 | -35.1 |
| 53078 | C4 | -23.4 | -29.9 | -38.2 | -38.9 | -46.5 | -40.9 | -41.6 | -43.7 | -40.3 | -40.9 |
| 53078 | C5C6 | -14.1 | -31.6 | -41.2 | -44.3 | -44.4 | -40.3 | -42.9 | -46.4 | -43.9 | -39.0 |
| 53078 | F1 | -11.5 | -28.5 | -34.9 | -40.7 | -43.3 | -43.6 | -44.7 | -43.2 | -43.0 | -42.1 |
| 53078 | F2 | -12.6 | -30.6 | -33.4 | -34.9 | -36.7 | -38.5 | -40.2 | -41.0 | -41.3 | -40.0 |
| 53078 | RG83 | - | - | - | - | - | - | - | - | - | - |
| 53078 | RG88 | - | - | - | - | - | - | - | - | - | - |
| 53078 | R5 | -28.2 | -41.7 | -44.5 | -48.0 | -48.8 | -44.6 | -46.5 | -44.9 | -43.4 | -45.7 |
| 53078 | R6 | -28.9 | -37.5 | -45.1 | -50.0 | -48.1 | -46.7 | -50.1 | -45.9 | -41.1 | -42.7 |
| 53078 | R7 | -26.9 | -34.5 | -37.6 | -41.0 | -40.2 | -39.1 | -42.6 | -40.7 | -38.9 | -36.4 |
| 53078 | R8 | -27.6 | -31.1 | -39.7 | -42.0 | -40.4 | -38.3 | -40.2 | -38.1 | -36.5 | -33.9 |
| 53078 | TX 3 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 4 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 8 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX 9 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX10 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX11 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX12 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX13 | - | - | - | - | - | - | - | - | - | - |
| 53078 | TX15 | - | - | - | - | - | - | - | - | - | - |

# SUMMARY

Experiments were designed and conducted to develop a data set for the analysis of relationships between remote sensing data and hydrologic variables and parameters. This particular series of experiments conducted in Chickasha, Okla., and Riesel, Tex., was successful. However, additional experiments are needed to cover a wider range of soil moisture conditions within semiarid areas. The conditions encountered here were relatively wet and a few sets of dryer condition observations are needed. In addition, experiments should be conducted within more humid climatic areas and areas with sandy soils. These results of aircraft remote sensing of soil moisture and hydrologic parameters are being published to aid researchers working in related areas.

# APPENDIX


# CHICKASHA, OKLA., SOILS MAPS, SAMPLING SITES AND TOPOGRAPHY
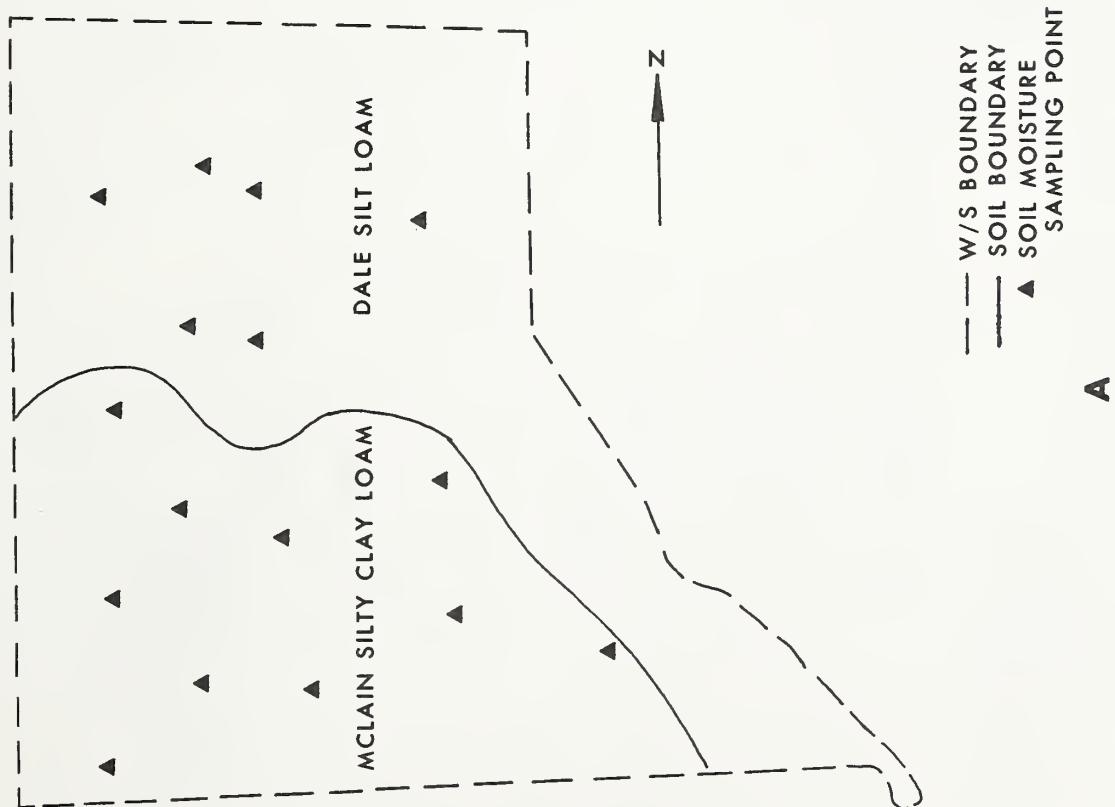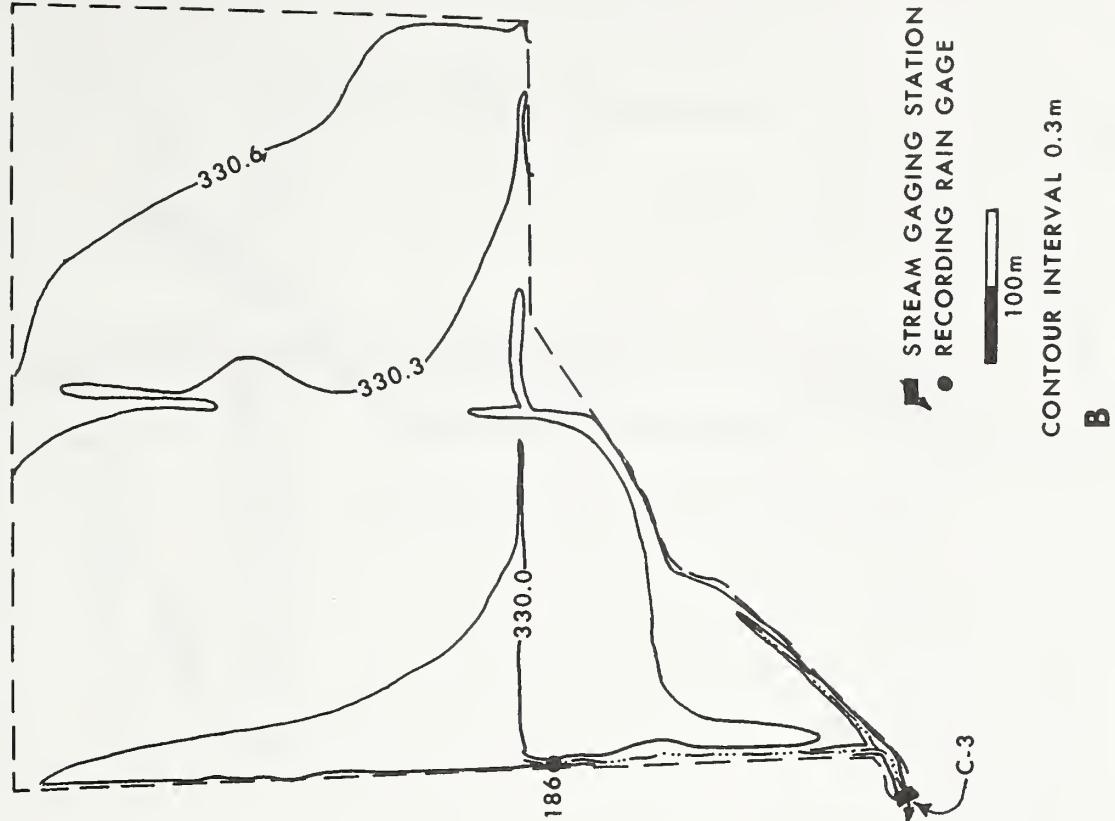
Figure 11.-- Watershed C3, Chickasha, Okla.: A, Soils and sampling locations; B, topography.
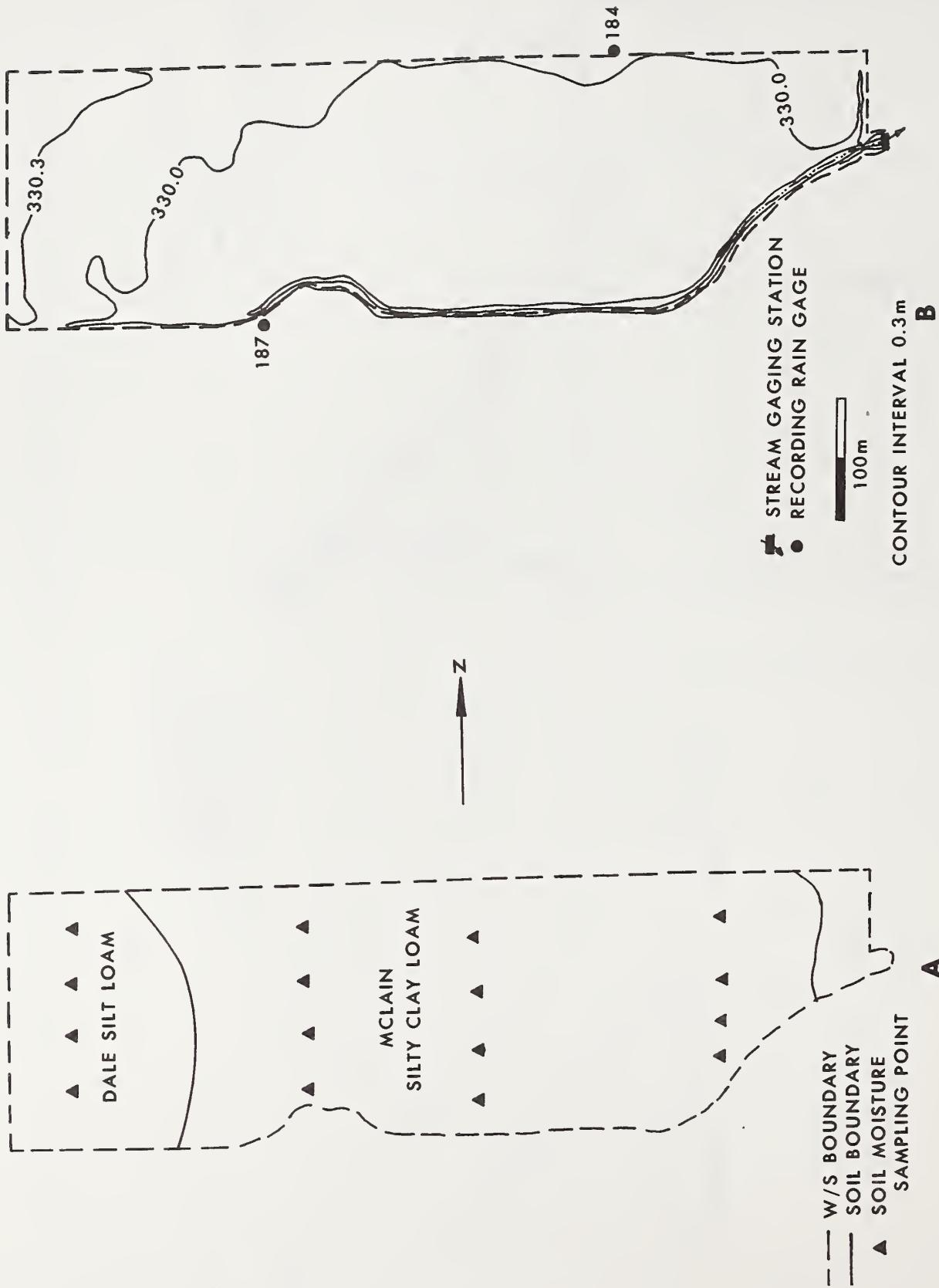
Figure 12.--Watershed C4, Chickasha, Okla.: A, Soils and sampling locations; B, topography.
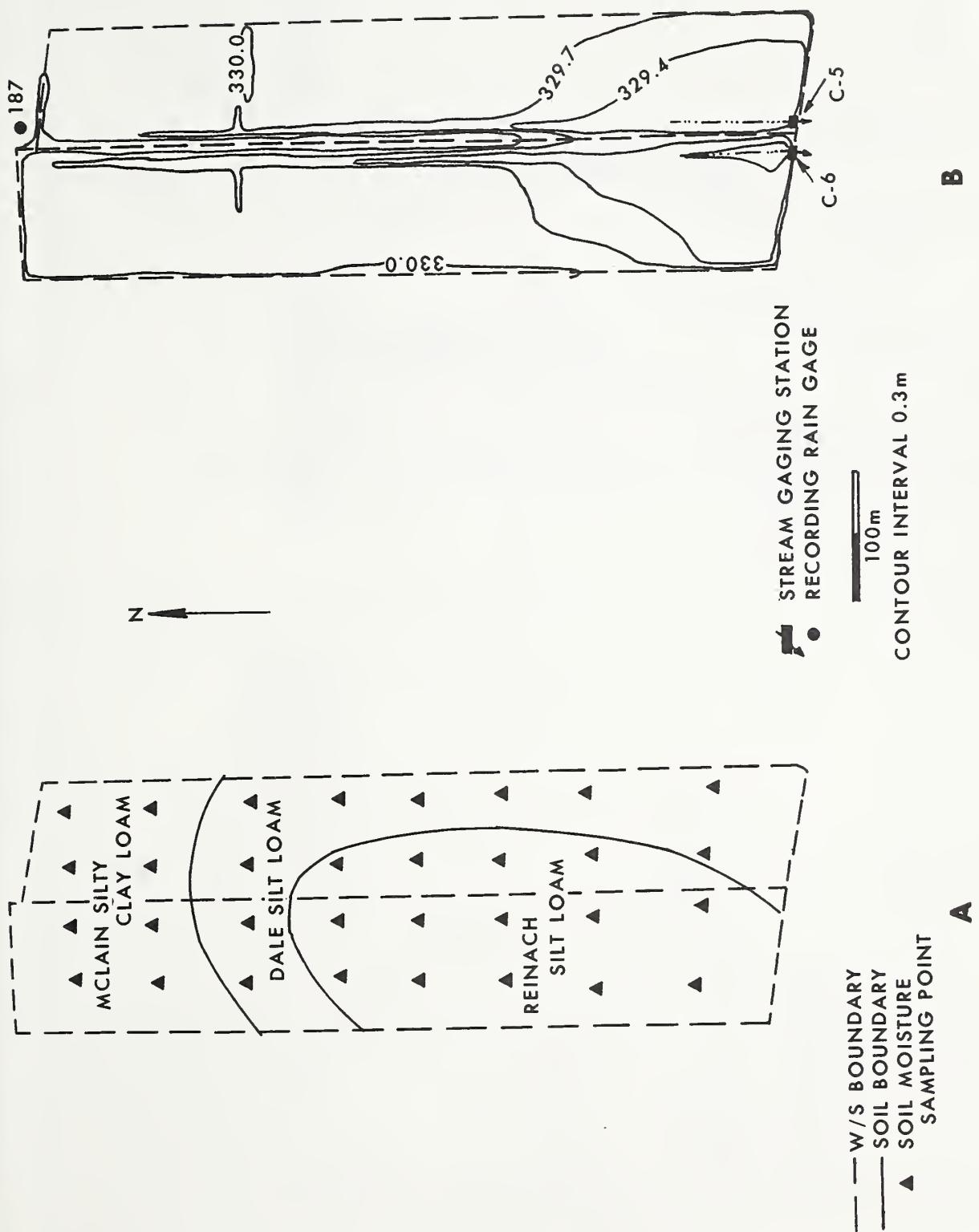
Figure 13.--Watersheds C5 and C6, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

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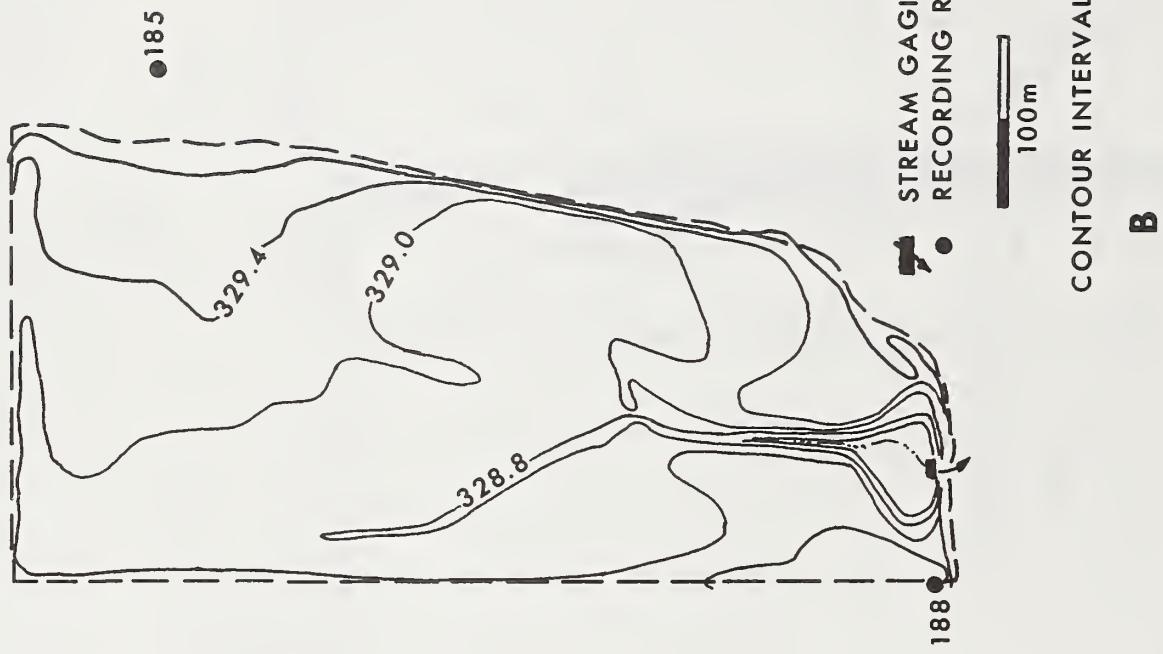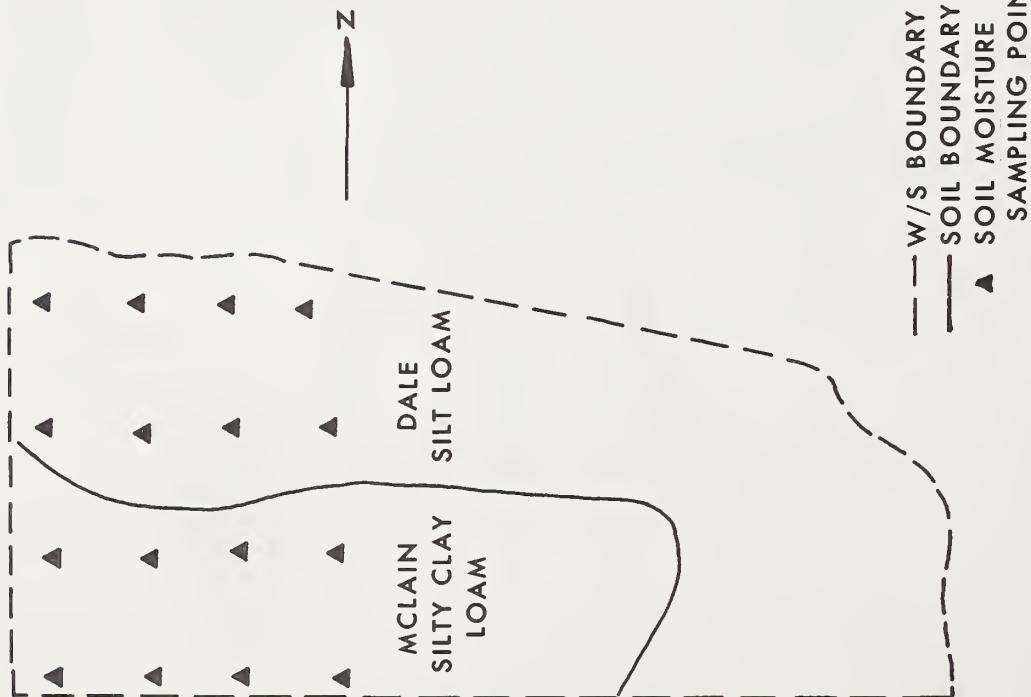
Figure 14.—Watershed C8, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

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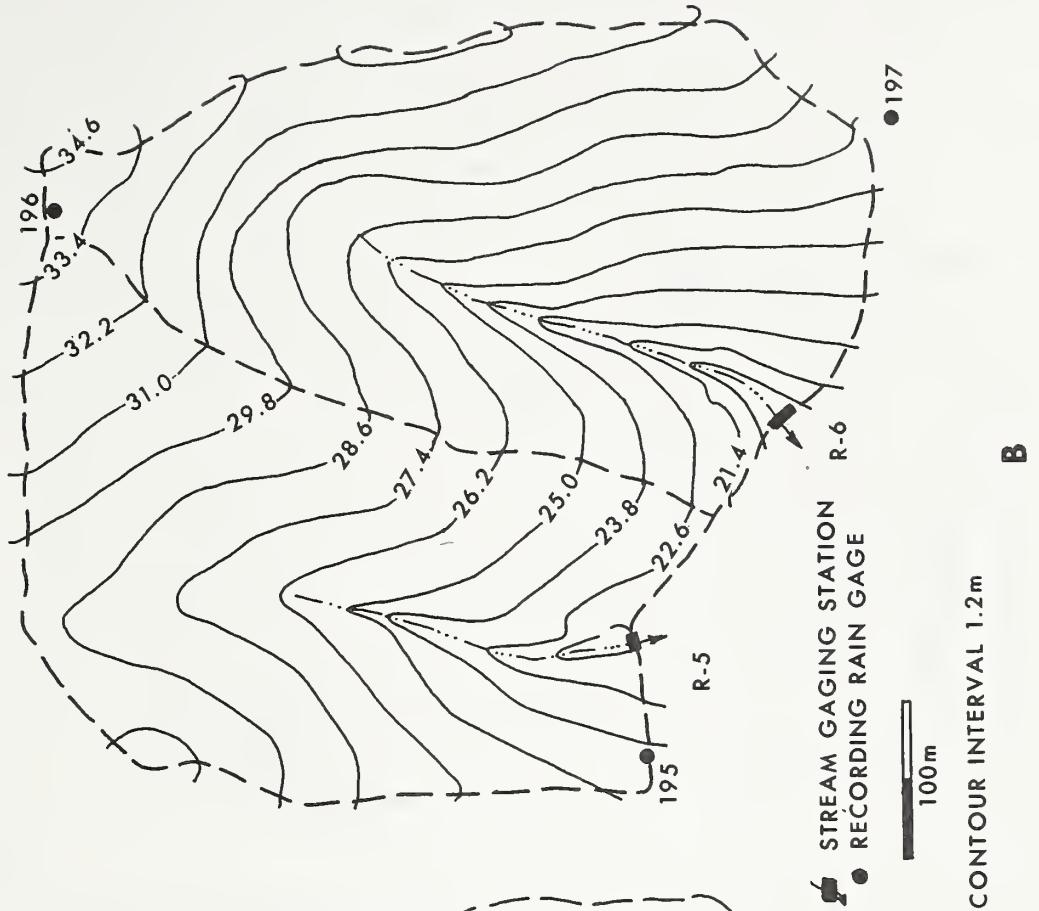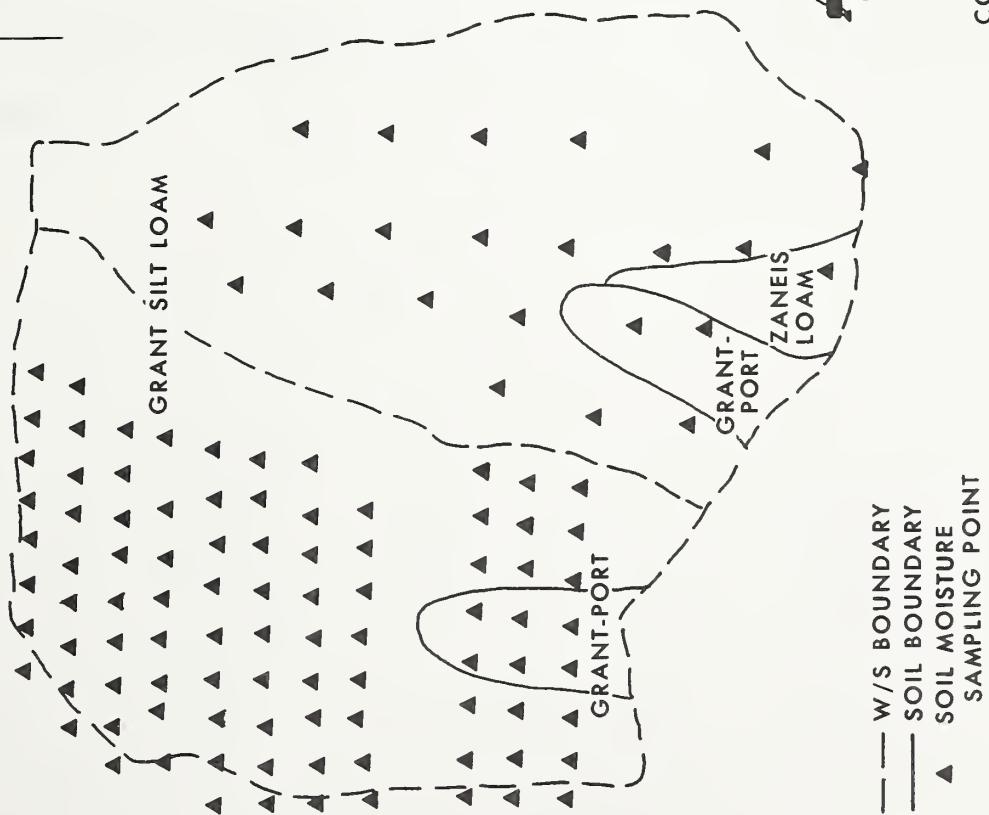
Figure 15.—Watersheds R5 and R6, Chickasha, Okla.: A, Soils and sampling locations; B, topography.
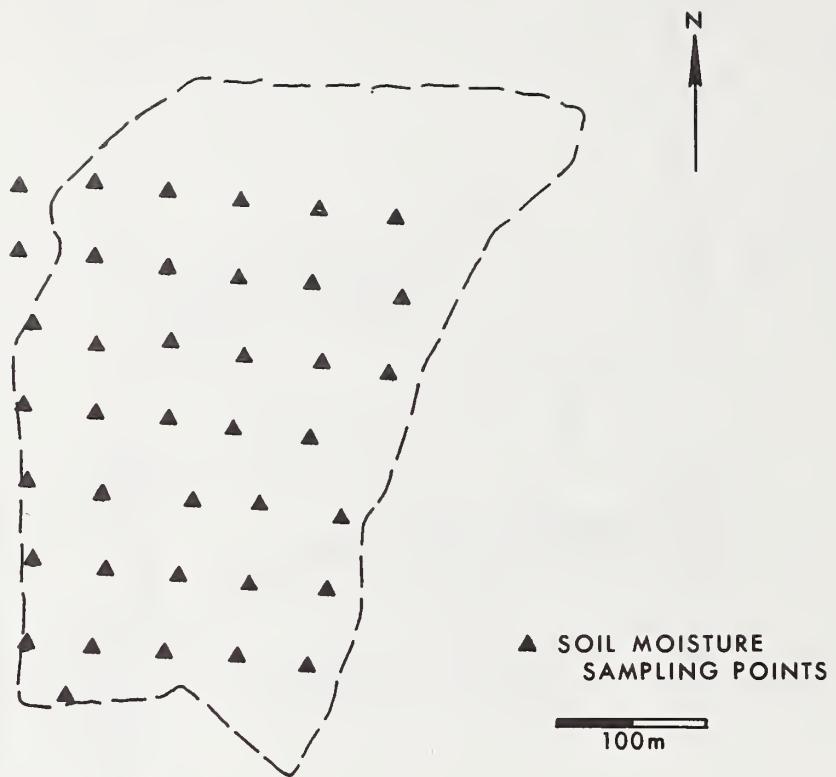
Figure 16.--Watershed R5, Chickasha, Okla., sampling locations
on May 12 and 30, 1978.

Figure 17.—Watershed R7, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

W/S BOUNDARY
SOIL BOUNDARY
▲ SOIL MOISTURE
SAMPLING POINT

RENFROW SILT LOAM

ZANEIS LOAM

A

▪ STREAM GAGING STATION
● RECORDING RAIN GAGE

100m

CONTOUR INTERVAL 1.2m

B

193

194

N

51

Figure 18.--Watershed R8, Chickasha, Okla.: A, Soils and sampling locations; B, topography.